# A Decision Support Framework for Sustainable Urban Planning in Developing Countries

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# Declaration

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# Abstract

Earth has a finite amount of resources; non-renewable materials like coal and oil are being depleted without any regard for their presence in the future. The human populace does not have a sustainable lifestyle. As of December 2020, there are an estimated 7.8 billion human beings on the planet, and by 2050, it is estimated to increase by 2.5 billion inhabitants; 90% of this growth will occur in Asia and Africa.

Initially a systematic literature review (SLR) was conducted to uncover the prominent challenges that urban planners face when tackling sustainable practices in developing countries. The starting point of the time frame was set to after the United Nations Conference on Sustainable Development's 2012 Rio+20 global summit. Therefore, only articles that were produced from 1 January 2013 until 31 March 2019 were included, as these would have adhered to the contributions and protocols set forth at this conference, viz., the largest UN Earth Summit, which was held in Rio de Janeiro in Brazil, in June 2012. In this study, therefore, a review was conducted of urban planning challenges and sustainable solutions or responses to these. The challenges were then grouped into topics that align with particular types of challenge. Then, the challenges were analysed to identify the well-known and disruptive challenges that restrict urban planners in developing countries. The top three unbiased urban planning challenges found from the SLR were urbanisation, urban sprawl and population growth.

Additionally, from the SLR, the tools and techniques that assist urban planners were identified and extensively categorised to differentiate among them. Consequently, 70 solution-specific tools and techniques, which contribute to the analysis and implementation of a sustainable context were determined to identify the best practices for sustainable urban planning. Thereafter, a multi-criteria decision analysis used an analytical hierarchy process to quantify the differences of the tools and techniques with regard to urban system elements and the sustainable development goals.

Evolving from the insights gained from the identification of the challenges and the tools and techniques, as well as the multi-criteria decision analysis, a requirements specification was established for a research product to achieve the aim of the study. This led to a functional analysis of the requirements specification to develop a decision support framework (DSF) that would achieve the aim of the research study. Based on this, the Sustainable Urban Planning Assistant Decision Support Framework (SUPA DSF) was designed.

Finally, the SUPA DSF was evaluated, which consisted of verification and validation. The verification was made up of two steps, i.e., evaluating the requirements specification, and conducting theoretical verification interviews with subject matter experts. The feedback from the interviews were refined into the SUPA DSF. Lastly, a validation of the SUPA DSF was performed by means of three case studies, one for each of the sustainable urban planning challenges identified in the SLR. These three challenges were urbanisation, urban sprawl and population growth. The SUPA DSF was validated for its relevancy and practicability.

# Opsomming

Die aarde het ŉ beperkte hoeveelheid hulpbronne; niehernubare materiale soos steenkool en olie word uitgeput sonder inagname van hul noodsaaklikheid in die toekoms. Die mensebevolking voer nie ŉ volhoubare bestaan nie. In Desember 2020 was daar ŉ geraamde 7.8 miljard mense op die planeet. Hierdie syfer sal na raming teen 2050 met 2.5 miljard inwoners styg, met 90% van hierdie groei wat in Asië en Afrika sal plaasvind.

ŉ Stelselmatige literatuuroorsig is eerstens in hierdie studie gedoen om die belangrikste uitdagings te identifiseer waarvoor stadsbeplanners te staan kom in die hantering van volhoubare praktyke in ontwikkelende lande. Die beginpunt van die tydraamwerk was ná die 2012 Rio+20-wêreldberaad van die Verenigde Nasies se Konferensie oor Volhoubare Ontwikkeling. Slegs artikels wat vanaf 1 Januarie 2013 tot 31 Maart 2019 geskryf is, is dus by die oorsig ingesluit, aangesien hulle sou voldoen aan die bydraes en protokols wat vir hierdie konferensie, die grootste Verenigde Nasies Aardeberaad, gehou in Rio de Janeiro in Brasilië in Junie 2012, uiteengesit is. ŉ Oorsig is dus uitgevoer van uitdagings vir stadbeplanning en die nodige volhoubare oplossings of reaksies. Die uitdagings is daarna in onderwerpe gegroepeer wat ooreenstem met die spesifieke soorte uitdagings, waarna die uitdagings ontleed is om die bekendste en mees ontwrigtende veranderinge te identifiseer wat stadsbeplanners in ontwikkelende lande kniehalter. Die topdrie- onsydige uitdagings vir stadsbeplanning wat in die literatuuroorsig geïdentifiseer is, was verstedeliking, stadskruip en bevolkingsgroei.

Die instrumente en tegnieke wat vir stadsbeplanners van hulp is, is ook uit die oorsig geïdentifiseer, en omvattend gekategoriseer ten einde hulle te onderskei. Sewentig oplossingspesifieke instrumente en tegnieke, wat tot die ontleding en implementering van ŉ volhoubare konteks bydra, is gevolglik bepaal om die beste praktyke vir volhoubare stadsbeplanning te identifiseer. Daarna is ŉ ontledingshiërargieproses vir veelkriteria-besluitontleding gebruik om die verskille tussen die instrumente en tegnieke ten opsigte van stadstelsel-elemente en die Volhoubare Ontwikkelingsdoelwitte te versyfer.

Op grond van die insigte verkry uit die identifisering van die uitdagings en die instrumente en tegnieke, asook die veelkriteria-besluitontleding, is ŉ vereistespesifikasie vir ŉ navorsingsproduk bepaal ten einde die doel van die studie te bereik. Dit het gelei tot ŉ funksionele ontleding van die vereistespesifikasie om ŉ besluitsteunraamwerk te ontwikkel. Die Sustainable Urban Planning Assistant Decision Support Framework (SUPA DSF) is op grond hiervan ontwerp.

Laastens is die SUPA DSF geëvalueer, welke proses uit verifikasie en geldigheidsbepaling bestaan het. Die verifikasie het twee stappe behels, naamlik evaluering van die vereistespesifikasie en uitvoer van teoretiese verifikasie-onderhoude met vakkundiges. Die terugvoering van die onderhoude is gebruik om die SUPA DSF te verfyn. Die geldigheidsbepaling van die SUPA DSF is uitgevoer deur drie gevallestudies, een vir elk van die uitdagings vir volhoubare stadsbeplanning wat in die literatuuroorsig geïdentifiseer is. Die geldigheid van die SUPA DSF is bepaal met betrekking tot die relevansie en uitvoerbaarheid daarvan.

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# List of acronyms

| | |
|---|---|
| 3Rs | Reducing, Reusing, and Recycling |
| AHP | Analytical Hierarchy Process |
| AI | Artificial Intelligence |
| BIA | Building Integrated Agriculture |
| BRT | Bus Rapid Transit |
| CCUA | Compact Coefficient of Urban Area |
| DSF | Decision Support Framework |
| FAR | Floor Area Ratios |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| GIS | Geographic Information Systems |
| GPS | Global Positioning System |
| ICLEI | Local Governments for Sustainability |
| ICT | Information and Communication Technology |
| IoT | Internet of Things |
| LEED | Leadership in Energy and Environmental Design |
| LiDAR | Light Detection and Ranging |
| LSM | Least Square Method |
| MCDA | Multi-Criteria Decision Analysis |
| MDFSA | Multi-Domain Fuzzy Sentiment. Analyzer |
| ML | Machine Learning |
| PALM | Parallelized Large-eddy Simulation Model |
| RS | Remote Sensing |
| SDGs | Sustainable Development Goals |
| SGN | Smart Growth Network |
| SLR | Systematic Literature Review |
| SMEs | Subject Matter Experts |
| SNM | Successful Neighbourhood Model |
| SSC | Smart Sustainable City |
| SSML | Stellenbosch Smart Mobility Lab |

| | |
|---|---|
| SUPA | Sustainable Urban Planning Assistant |
| SUPA-DSF | Sustainable Urban Planning Assistant Decision Support Framework |
| TOD | Transit Orientated Design |
| TVEs | Township and Village Enterprises |
| UN | United Nations |
| UPA | Peri-Urban Agriculture |
| USA | United States of America |
| WSUD | Water-Sensitive Urban Design |

# Chapter 1: Introduction

This research is concerned with an investigation into sustainable urban planning to identify and select appropriate, adequate and suitable techniques to support urban planners in developing countries. This chapter outlines the introduction and background into the research problem. Then, the problem statement, research aim and objectives are presented. Thereafter, the philosophical approaches for the project are outlined. Then, describing the research approach intended for this research. Lastly, the scope and ethical implications.

## 1.1 Introduction and background

Urban planning in developing countries was established according to the practices and traditions formed in developed countries and still holds a strong impact on current institutions of planning (Currie and Musango, 2017). This is problematic given that countries in the developing world were developed in very different circumstances than the developed countries (Horn, 2015). Therefore, it is unlikely that the developing world will follow the same or similar urban planning customs as those of the developed countries and anticipate or expect the same success (Horn, 2015). Therefore, from a methodological point of view, developing countries need to adapt to their specific context and renew their urban planning practices to fit a sustainable agenda.

Urbanisation is the phenomenon of rural migration to urban areas (Ding *et al.*, 2015; Brelsford *et al.*, 2017). This occurs usually when people seek better quality of life for families by seeking higher paid employment in cities. "*The African population is expected to reach 770 million urbanites by 2030*" (Currie and Musango, 2017, p. 1263). Africa's urban population currently stands at 550 million. Furthermore, Africa currently only has seven megacities (a city with population greater than 10 million inhabitants), namely, Cairo (Egypt), Accra (Ghana), Khartoum (Sudan), Kinshasa-Brazzaville (Democratic Republic of the Congo and Republic of the Congo), Lagos (Nigeria), Nairobi (Kenya) – and Johannesburg-Pretoria (South Africa). However, in the next 10 years, it is predicted that Africa will gain 12 new megacities (Horn, 2015). This extent of urbanisation is unprecedented and requires plenty of groundwork (such as incorporating more sustainable practices suited for developing countries) to be laid, which, some researchers argue, developing countries are not prepared for (Department of Economic and Social Affairs, 2014; Horn, 2015). These preparations require infrastructure and expertise regarding sustainable urban development. Ensuring the sustainability of a city requires the habits of production and consumption to undergo a fundamental change from the present system of consumerism to a collaborative structure of social, technological and ecological elements (Broto, 2017).

Urban systems are challenged to pursue a balanced development strategy (Wendt, 2015). Moreover, this balanced strategy brings difficult choices of trade-offs between social, environmental and economical directives (Bibri, 2018). Developing countries are challenged with improving social unity, quality of life and sustainability, but economic success is the core and an urgent need (Chang and Sheppard, 2013; Ding *et al.*, 2015).

With automobiles becoming cheaper, people do not need to live near their jobs, and can seek cheaper accommodation in the outskirts of cities. However, this trend to seek more green spaces and less dense living areas on the periphery of towns and cities led to urban sprawl (Randhawa and Kumar, 2017).

Urban sprawl is where "*cities extend into rural areas and large areas of land are developed in a low-density pattern*" (Frumkin, 2016, p. 201). Alongside the risk of urbanisation is harming the quantity and quality of arable land, which begins a cycle of growth-degradation for developing countries (Ding *et al.*, 2015). There are many different methods worldwide that have been developed to counter the challenges of urbanisation and urban sprawl. For the purposes of the research, the methods will be known as tools and techniques. For example, smart growth is an urban planning practice that prioritises transit-oriented development. Moreover, smart growth aims to provide multi-modal transport opportunities to residential areas (Randhawa and Kumar, 2017). In most cases, suburban areas are low density areas that do not have enough public transport or bicycle lanes. This immediately leads to an automobile-dependant lifestyle due to poor urban planning (Litman, 2014). The focus of smart growth is to enhance liveability for the current generation (Artmann *et al.*, 2019). It is very important to understand the consequences that arise from unplanned urban expansion. Such enlargement of cities distorts urban ecosystems, creating socially contentious places to live by imposing different cultures to mix, and it increases the demand for energy that come from cheap unsustainable resources (Laffta and Al-Rawi, 2018). Fossil fuels are used by all developing countries because they are the cheapest option provided by developed countries. Therefore, developing countries need to transform the way they produce energy before the fossil fuels are used up, which would cause a massive delay in their local energy generation. This identifies that multiple tools and techniques should be investigated for suitability of different developing country cases.

There is now an opportunity for developing countries due to the generation of large amounts of data and high-speed processing using green technologies. Green technology refers to technologies that can have a positive impact on the environment. There are four eco-technologies that are used by professionals in the urban planning field: Environmental Technologies, Information Technologies, Geographical Information Systems and Communication Technologies (Laffta and Al-Rawi, 2018). These are nothing new in the world of technology as they were developed 10-15 years ago, but it is necessary to understand how these can create opportunities for sustainable problem solving. These technologies will be discussed further in this project because an end goal is to discover the best practice to utilise for achieving sustainable urban planning in developing countries.

Pressure is placed on existing services and infrastructures within cities due to the disruption of rapid urbanisation, especially in developing countries (Chang and Sheppard, 2013; Ding *et al.*, 2015; Randhawa and Kumar, 2017). It is important to understand these effects and plan to avoid or adapt to them. Urban planning has been a very important profession over the last few centuries. Designing our cites in ways that allow people to live, work and play in an urban environment is a serious endeavour. Socio-ecological elements are known as components that are coupled to benefit from services of human agency on ecosystems, vice a versa (Vallejos *et al.*, 2020). The resilience of a sustainable system is balanced on the socio-ecological aspects; only by maintaining and enhancing these aspects, can the economical features be developed. Developing countries are known for their high crime rates, which stem from unsustainable urban growth, leading to unemployment and food insecurity within the poor community (Moroke, Schoeman and Schoeman, 2019). Figure 1.1 reveals the balance needed to achieve sustainability.

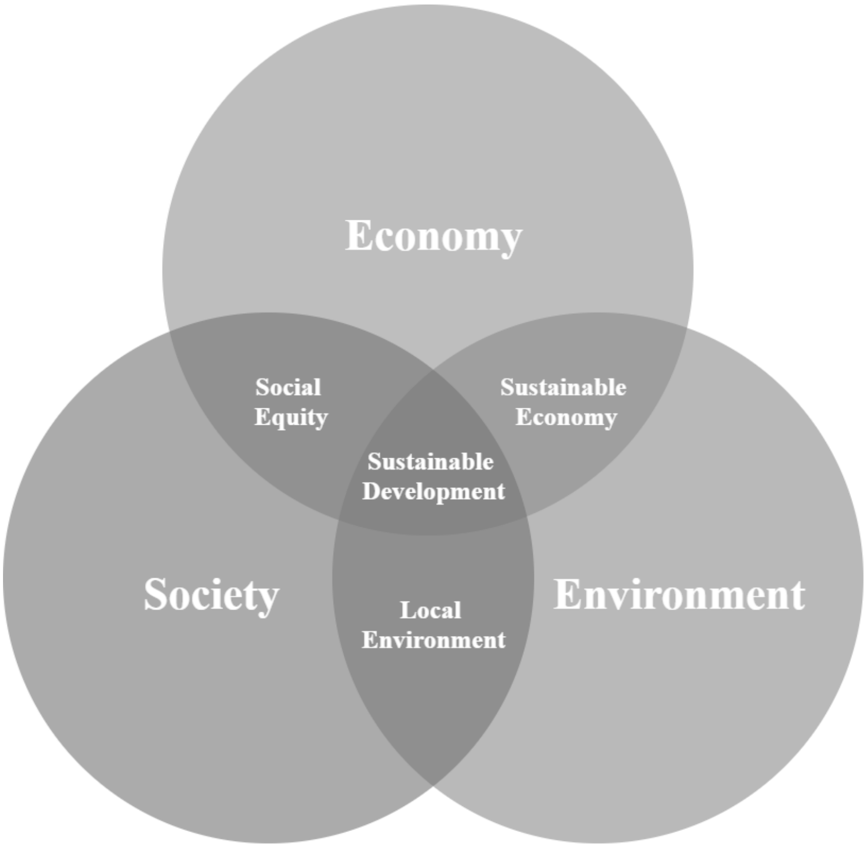



*Figure 1.1: Sustainable development Venn diagram. Source: (Frescoryl, 2018)*

The drive of development in cities follows the principles of wealth creation, but for this to be sustainable, it requires a 'Sustainable Economy' and advancements in 'Social Equity', as seen in Figure 1.1 (Frescoryl, 2018). "*Within the current political landscape of South Africa 'all development is good development as long as your development will promote job creation'*" (Pulker, 2016, p. 88). Referring to this statement when looking at the above diagram, job creation and development form 'Social Equity' together with social inclusion and communities, but the environmental aspects are rarely considered. "*Societal development performs poorly in protecting the environment and improving the quality of people's lives*" (Bibri, 2018, p. 779). Developing countries in Africa are far from this balanced state. African mall development, for instance, is more driven by economic benefits, rather than by urban planning values (Battersby, 2017). Creating evidence that urban planning objectives in developing countries are led by economic agendas. Therefore, urban planning techniques need to contribute to all factors of sustainability, especially with the rise of urbanisation in developing countries.

One prevalent issue with urban planning when addressing the complex system of a city is that it is impossible to make long-term predictions. Sustainable urban planning requires professionals in these fields to have the computational technologies and adept analytical capabilities to traverse the complicated multidisciplinary field (Bibri, 2018). It is important to understand this challenge because achieving a sustainable city requires a system perspective. Different methods have used sustainable indicators to conduct sustainability assessments. However, this is not enough and it is time for a new method to capture all the elements of these complex urban systems (Dur, Yigitcanlar and Bunker, 2014). The research seeks to increase the availability of tools and techniques for urban planners related to a developing country context.

A recurring theme that was addressed in this study relates to developing countries. The challenges associated with these countries also arise when comparing sustainable urban planning practices worldwide. It is evident there is a huge divide between income levels all over the world. "*In South Africa, the proportion without income is observed at 12%; those with less than R6400 per month are 59.5%; and the highest income group (greater than R51200 per month) gathers 3%*" (Musango, 2014, p. 309). Furthermore, "*household respondents whose fuel cost is R101-500 per month are in the income category R801-1600 per month*" (Musango, 2014, p. 313). This statistic suggests that approximately 40% of their income is needed for transport alone which is clearly unsustainable. Under such conditions, the wealth gap is never going to be overcome because of the challenges surrounding urban sprawl and urban planning. Urban sprawl and the lack of urban planning restrictions is the reason for high transport costs because workers need to commute into town to work in the inner city. The link between these factors (the wealth gap between the haves and the have-nots and urban sprawl) is inherent in traditional urban planning. People who have wealth and hold power, such as government officials and the 3% of high income earners, used their economic advantage to mould the urban planning agendas in their favour (Horn, 2015). Over decades of this segregation occurring, unplanned informal settlements have appeared on undeveloped land on the peripheries of cities (Mbow *et al.*, 2008). Since urban planners had not foreseen the threat of urbanisation, they might be to blame for the existence of lower income residents within the informal settlements, who only want the economic benefits of cities, but who are forced to spend 40% of their income toward transportation to and from their jobs in the cities. This challenge overflows into other issues, such as GHG emissions from increased automobile use, and social inequality, as lower income individuals are not given an opportunity to lift themselves out of poverty due to past urban planning mistakes. This argument enforces the evidence that urban planning objectives follow economic agendas.

Urbanisation is not completely a negative trend. In the developing world context, urbanisation can be a source of economic growth. In many cases, developing countries have sufficient land available to continue development outward from the city. In developing countries, any economic growth is seen as good growth (Horn, 2015). This misinterpretation of growth does not acknowledge the risks of unsustainable growth. Large opportunities may lie ahead for developing countries regarding rapid urbanisation. However, this research intends to illuminate the future challenges that lie ahead if the decision makers only follow their economic agendas without simultaneously considering the perspectives of social and environmental improvement too. Consequently, the research also seeks to increase the transparency of the effects of sustainable urban planning challenges. Therefore, proving the importance of quality sustainable urban planning tools and techniques to mitigate the challenges.

## 1.2 Problem statement

Broadly speaking, a need exist for sustainable urban planning practices, that considers all three dimensions of sustainability. Furthermore, current urban planning practices in developing countries are led by economic agendas and do not prioritise social and environmental advancement equally. An array of tools and techniques that aim to equally advance the sustainable agenda for developing countries does however exist – but, such tools and techniques need to be optimised to address the current challenges that urban planners face in developing countries.

## 1.3 Research aim and objectives

The aim of this research is to contribute towards the successful transitioning of cities towards sustainability, and to support the mitigation of the challenges associated with developing countries' urban planning through the development of a research product that assists urban planners to select appropriate urban planning tools and techniques to ensure that consideration is given to social, environmental and economic agendas, in order to support sustainable urban planning.

To achieve the stated aim, the following four objectives have been defined:

RO1: Perform a systematic literature review (SLR) to understand the challenges associated with sustainable urban planning in developing countries. Sub-research objectives associated with RO1 include:

i. Using a Boolean search with synonyms of (urban planning, challenges & sustainability) to identify the prevalent challenges that disrupts sustainable urban planning;
ii. Disseminate the challenges from all the relevant literature review papers to determine the prevalent topics; and
iii. Identify connection of urban system elements and sustainable development goals to the challenges to quantify tools and techniques using a multi-criteria decision analysis (MCDA).

RO2: Determine the appropriate tools and techniques to support effective and efficient sustainable urban planning in developing countries. Sub-research objectives associated with RO2 include:

i. Investigate the existing tools and techniques that are used for urban planning today;
ii. Categorise tools and techniques that assist urban planning specific to sustainability practices to create definitions for the MCDA; and
iii. Perform a MCDA combining the urban system elements and SDG to quantify tools and techniques for differentiation in the research product's assessment for suitable tools and techniques for urban planners in developing countries.

RO3: Develop a requirements specification to design a research product. Sub-research objectives associated with RO3 include:

i. Determine the functional requirements, user requirements, design restrictions, attention points and boundary conditions to perform a requirements specification for the research product; and
ii. Undertake a functional analysis of the requirements specification to design the research product.

RO4: Develop and evaluate a research product for sustainable urban planning in developing countries. Sub-research objectives associated with RO4 include:

i. Develop a research product that will address the aim of the study according to the requirement specification and functional analysis; and
ii. Evaluate the developed research product with two parts:
    a. Verification of the requirements specification and a theoretical verification using interviews with subject matter experts (SME),
    b. Validation with case studies to identify the relevancy and practicability of the research product.

## 1.4 Philosophical approach

Context is very important for sustainability. There has not been sufficient research on understanding the context of the decision-making process for urban planning in developing countries to enable us to identify patterns or structures. Without such structure and context, achieving sustainability in these countries becomes very difficult. A philosophical approach is thus necessary to show that the research was thorough with a particular perspective in mind, rather than just developing a product. Table 1.1 shows 4 different philosophical approaches that are commonly used in research, namely, positivism, critical realism, postmodernism and pragmatism, while elaborating on their principle orientation, research strategy, epistemology, and axiology (Saunders, Lewis and Thornhill, 2009).

*Table 1.1: Philosophical approaches. Source:* (Saunders, Lewis and Thornhill, 2009)

| | **Principle orientation** | **Research strategy** | **Epistemology** | **Axiology** |
|---|---|---|---|---|
| **Positivism** | Researcher maintains an objective view and builds a proposition that is widely tested | Quantitative methods | Scientific with observable and measurable facts | Researcher is unbiased and impartial (Objective) |
| **Critical realism** | Realism is influenced by history concentrating on evaluation of opposing ideas. Researcher accepts the bias of his/her world view to minimise bias errors | Quantitative and qualitative methods | Knowledge is historically situated and transient | Researcher is as objective as possible but recognizes the bias of his/her world view (Objective) |
| **Postmodernism** | Researcher wishes to question the recognized ways of thinking and to analyse data to reveal variabilities | Qualitative methods | What counts as 'truth' and 'knowledge' is decided by dominant ideologies | Researcher and research are rooted in power relationships (Subjective) |
| **Pragmatism** | Researcher recognises that there are many ways of understanding the world, and that a single point of view cannot give the entire picture in the case of various certainties | Range of methods, i.e., mixed, multiple, qualitative, and quantitative | Focuses on problems, practices, and relevance | Research is introduced and sustained by researcher's questions and ideas (Objective and Subjective) |

In this research, the pragmatic philosophical perspective is adopted because the researcher understands that there are many trade-offs necessary when interpreting the world and a holistic view is important. The pragmatic perspective led the researcher to address problems with a combination of quantitative and qualitative research methods. The researcher also acknowledges that the problem that this research sought to address can be interpreted in various ways, and that the solutions suggested, although they have been established in a structured, systems engineering approach, are not the only option to address the problem. Rather, they show a specific point of view of the problem space (i.e. balancing the sustainable urban planning practices in developing countries).

## 1.5 Research approach

To address the research aim – that is, to contribute towards the successful transitioning of cities towards sustainability, and to support the mitigation of the challenges associated with developing countries' urban planning – a systematic research approach is required. It is important to allow for a structured approach to deal with the complexity of large multi-criteria systems. Therefore, a systems engineering approach was used as an overarching research strategy.

Systems engineering is defined as an interdisciplinary approach that facilitates with transforming of operational needs into system-level solutions that satisfy shareholders expectations (US Department of Defense Systems Management College, 2001). Systems engineering is a comprehensive and replicative problem-solving technique that is used to interpret needs and requirements into a system solution (US Department of Defense Systems Management College, 2001).

The systems engineering approach consists of four phases, namely: (i) input identification, (ii) requirement analysis, (ii) functional analysis, and (iv) design synthesis (US Department of Defense Systems Management College, 2001). Each phase has its own subsections, which are introduced below, and an illustrative outline is given in Figure 1.2 to explain the process.

### 1.5.1 Input identification

This phase identifies and investigates the context for factors that influence the research, i.e. sustainable urban planning challenges in developing countries and sustainable urban planning tools and techniques (refer to RO1 and RO2. Urban planning practitioners must deal with tools and techniques to address the sustainability challenges that occur within the city system. During the input identification process, a SLR is used to contextualise these factors (i.e. urban system element and sustainable development goals). Subsequently, the challenges and the tools and techniques were synthesized to produce a landscape relating to the context of sustainable urban planning in developing countries. Chapter 2 and Chapter 3 report on the challenges and the tools and techniques respectively.

### 1.5.2 Requirement analysis

After the inputs have been identified and assessed, the requirements that will guide the development of the research product need to be analysed. This phase of the systems engineering approach required a quantitative assessment to determine the appropriate factors that will facilitate an effective research product within the research context. An analytical hierarchy process (AHP) is thus implemented to determine the tools and techniques that will best address each sustainable urban planning challenge (refer to RO2). The AHP is reported on in Chapter 4. A requirements specification is developed in Chapter 5 (refer to RO3, part (i)), using five requirement types (Huff, Tranfield and Van Aken, 2006): (i) functional requirements, (ii) user requirements, (iii) design restrictions, (iv) attention points and (v) boundary conditions.

### 1.5.3 Functional analysis

The functional analysis looks at the functional processes that would best suit the requirements specification in the previous phase. Functional flow block diagrams were thus developed, using the content analysis of Chapter 3, the multi-criteria decision analysis of Chapter 4, and the requirements specification in Chapter 5. The identified functional processes were synthesised to develop a framework that outlines the foundational features of the research product (refer to RO3, part (ii)). This functional analysis phase was reported on in Chapter 6.

### 1.5.4 Design synthesis

The last phase will be separated into two parts (Part A and Part B). Part A involved designing the research product into a decision support framework, utilising the requirements specification and the functional analysis. Part B was the evaluation process, which was split into two stages, verification and validation (refer to RO4). Stage 1 comprised a two-step verification procedure: firstly, evaluating the requirements specification, and secondly, presenting a theoretical verification to SMEs. The verified framework was helpful in assisting the development of the research product, which included making refinements to the research in response to useful feedback from the SMEs. Stage 2 of the evaluation process consisted of validation via case studies, which entailed validating the relevancy and practicability of the developed framework. The last phase of the systems engineering approach is reported on in Chapter 7 and Chapter 8.

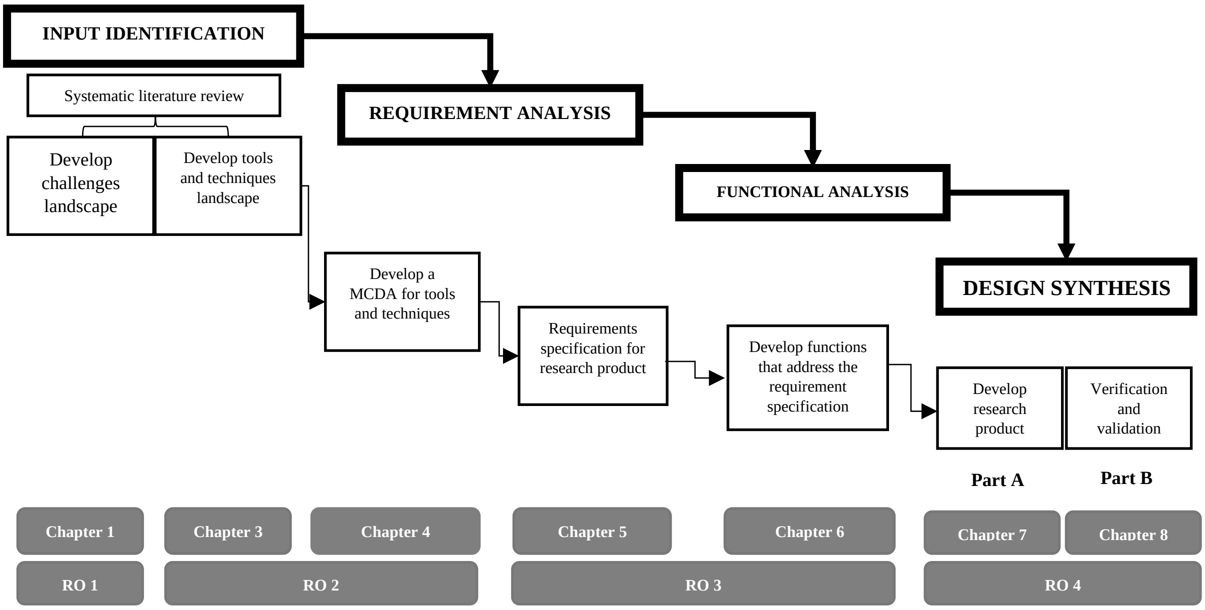



*Figure 1.2: Thesis schematic*

## 1.6 Research scope

In this section, the scope of the research is outlined and the assumptions that are made are stated. Furthermore, the limitations and delimitations of this research study is presented.

The aim of this research is not to develop new technology but to interlink the existing technologies (i.e. tools and techniques), based on the concepts of sustainable urban planning. This research can be used by either researchers or planning practices aiming to contribute towards more balanced sustainable city developments and achieve a greater number of successful transitions to sustainable planning practices.

### 1.6.1 Limitations

The SLR is used to disseminate the challenges from all the relevant literature review papers to determine the prevalent topics that contribute to sustainable urban planning. The research will use the top three prevalent challenges found in literature since 2013 to continue evaluations such as verification and validation of the research product.

In any research, the context is important. The approach of the research is thus to provide support and to contribute to a successful transition to more sustainable cites in developing countries. The intention is not to deliver a final step by step solution that decision makers can use to implement in their respective projects, but rather, to provide them with an appropriate tool or technique for consideration to create a more sustainable balance in an urban system.

### 1.6.2 Delimitations

The feasibility and applicability of the final provided tool/technique for the sustainable urban planning project should be investigated by the user within his or her specific context. This extra step is necessary because the SUPA DSF does not assess the operational or financial requirements in depth for real-world implementation of the recommended tool or technique.

## 1.7 Ethical implications

Due to the intended focus on urban planning, no ethical implications are expected to come to light. The research literature does not contain sensitive information of either a corporate or a personal nature. The research will use published literature sources to develop the theory in order to produce a solution for sustainable urban planning. An ethical conflict does appear in the form of bias regarding the advancement of social equity and environmental stability in the sustainability triple bottom line. Therefore, the research will thus attempt to define each element (environmental, social and economic) sufficiently to show visibility of decisions in solution development. Lastly, within the verification process, interviews were conducted to gather feedback, and no ethical impacts were brought to the surface during such interviews.

## 1.8 Conclusion: Chapter 1

The research elaborated on the challenges that developing countries are facing in view of urbanisation. The research identified the issues of sustainability that arise in response to rapid urbanisation; urban planning is seen as the largest threat but also the greatest opportunity to solve these issues. Therefore, the research began by investigating the current urban planning practices to identify both their benefits and limitations of sustainable urban planning scope before looking at new tools and techniques that will increase the chances of a successful transition to more sustainable urban planning practices. The context of developing countries requires in-depth insight in order to identify and overcome their unique difficulties.

After the background to the problem was discussed in this chapter, the problem statement, aim and objectives were identified. Thereafter, the overall philosophical approaches were discussed. Then, the research methodology was introduced; this included the systems engineering approach, which will be used to identify the four phases that will together enable the researcher to achieve the aim and objectives of the research. Lastly, the, scope, limitations and ethical implications.

Chapter 2 will focus on the systematic literature review (SLR) and the challenges associated with the sustainable urban planning in developing countries. Thereafter, investigating the urban system elements and the sustainable development goals versus the 3 prominent urban planning challenges found by the SLR.

# Chapter 2: Sustainable urban planning challenges

The first research objective is to conduct a systematic literature review (SLR) of challenges faced by urban planning in relation to sustainability. A significant portion of this chapter was published as a journal article in a 2019 issue of the *South African Journal of Industrial Engineering* (SAJIE)[1]. The article was submitted by the author, titled *"A systematic literature review of the sustainable urban planning challenges associated with developing countries"*.

The aim of the SLR is to identify the prevalent challenges faced by urban planners in relation to sustainability. To achieve this, four steps were followed: (i) perform a SLR using a Boolean search with synonyms of key words, namely, urban planning, challenges & sustainability, (ii) gather together the challenges from all the relevant literature review papers and display them in a matrix of urban planning topics relating to sustainability, (iii) group together the prevalent topics, focusing on the challenges that occur the most frequently, and (iv) identify the connections between urban system elements, the United Nations' Sustainable Development Goals (SDGs) and the challenges.

In this chapter, introducing the SLR with the approach it will follow. Next is the bibliometric analysis for the research papers produced worldwide and where there conducted their studies. Then, the discussion of the related challenges found in the SLR for sustainable urban planning. Lastly, grouping and linking the sustainable urban planning challenges to urban system elements and sustainable development goals.

## 2.1 Introduction to the systematic literature review

Urban planning is a very old profession. It arose when people began to gather together for practical reasons, bringing resources, security, and amenities closer to more people (Bibri, 2018). However, in the 21st century, traditions have changed rapidly, and cities need to be resilient in the face of urbanisation and population growth. Sustainability is the buzz word that is now constantly found in master city plans. But do city planners really know what this entails? Do they understand how to balance the environment with the economic, social, and political ideals of the city to create a stable and resilient future?

There seems to be a lack of consensus among urban planning practitioners about how to implement sustainable practices in urban development (Shummadtayar, Hokao and Iamtrakul, 2013; Mohareb, Derrible and Peiravian, 2016; Bibri, 2018; Grădinaru *et al.*, 2018). Implementing sustainable practices is a difficult task, and it is imperative to prevent the negative aspects of unsustainable situations from prevailing into the next generation. Particularly considering the exponential growth of technology related to urban planning, it is very important to use the potential benefits in the urban development landscape.

In accordance with the philosophy of pragmatism (see Section 1.4), this research sets out to investigate the problems associated with the sustainable urban planning in developing countries. It seeks to identify the urban planning challenges that arise when planners attempt to follow sustainable principles and to

[1] (Jooste, de Kock and Musango, 2019), DOI: 10.7166/30-3-2247

put them into practice. The study thus began by using a SLR as a structured process to gather relevant research papers on a specific theme.

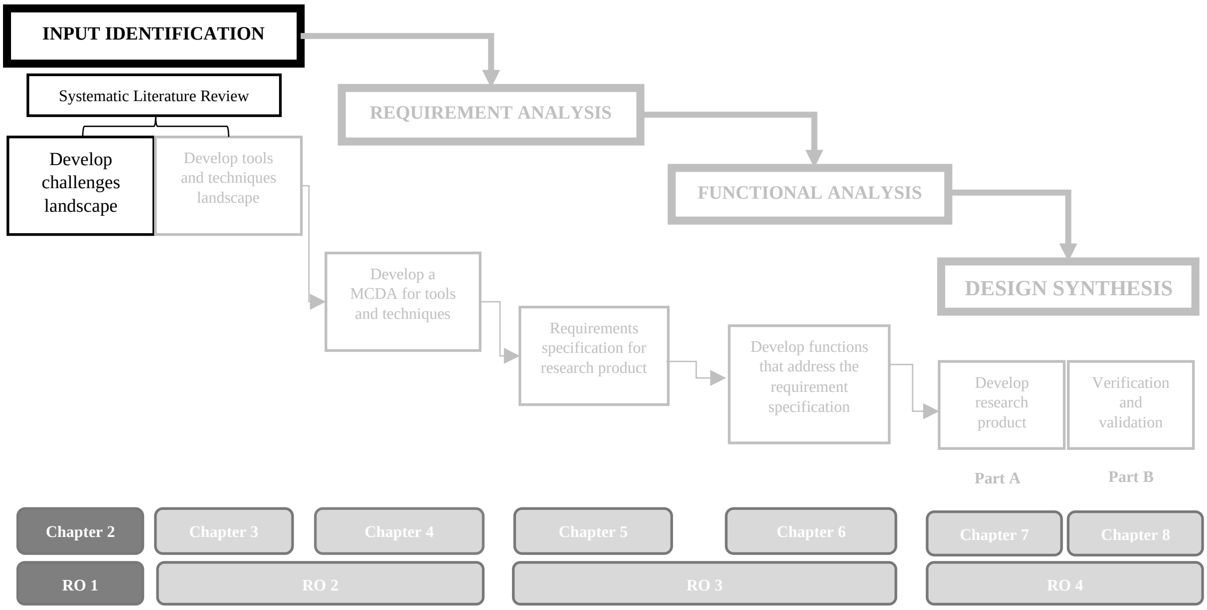



*Figure 2.1 Thesis schematic (Chapter 2)*

The challenges related to sustainable urban planning were identified in relevant research papers and synthesised into a large table. With the assistance of this summary table (found in Appendix A.1), the pertinent challenges that prevent urban planners from designing and managing cities sustainably could be identified.

The first section of the chapter explains the process of conducting a SLR from posing the review questions to showing how the information was extracted. This covers the first research objective as shown in Figure 2.1. This is followed by a brief analysis of the challenges that appear frequently, together with a synthesis of the findings that will be investigated. A bibliometric analysis was used to identify where the research was conducted and which developing country was studied. Furthermore, urban system elements and sustainable development goals (SDGs) were identified to quantify sustainability in the multi-criteria decision analysis (MCDA) of Chapter 4. The chapter concludes by answering the review questions and discussing further research.

## 2.2 Systematic literature review approach

A systematic literature review (SLR) is a procedurally rigorous examination of research results available in the literature (Kitchenham, 2007). The beginning of such a review starts by creating a foundation of knowledge. A systematic review is a review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review (Moher *et al.*, 2009). The difference between a typical literature review and an SLR is found in the fundamental approach. An SLR follows a method that is set out before the review begins, and contains several steps, including extraction and synthesis. An SLR begins with a Boolean search, which refers to sifting through a large database of research articles by using a group of synonyms for the theme under review (see Table 2.1).

Next, the group of identified research papers is scrutinised more closely to ensure their relevance to the intended theme. See Figure 2.3 for the SLR search flowchart followed herein. In our case, then, the challenges relating to sustainable urban planning were extracted from each paper; this is discussed further in Section 2.4. Lastly, the challenges were synthesised by tallying the number of challenges in each topic. This synthesis phase of the SLR was divided into three parts:

i. Urban planning challenges;
ii. Urban system elements; and
iii. Sustainable development goals (SDGs), as defined by the United Nations General Assembly in 2015.

Evaluating the challenges in combination with urban system elements and SDGs provides the knowledge that will assist us in comparisons that identify the appropriate requirements, which will be discussed in Chapter 5. The output of the requirement identification will be a requirements specification.

### 2.2.1 Literature review questions

The literature review research questions addressed by this study were:

i. What research topics on sustainable urban planning are being addressed in the existing literature?;
ii. How effective is the SLR?; and
iii. What are the limitations and biases of the SLR?

### 2.2.2 Search strategy

The literature search was conducted using the Scopus database. The search strings are presented in Table 2.1.

*Table 2.1: Boolean search strategy*

<table>
<tr><td>Urban planning</td><td rowspan="4">AND/OR</td><td>Challenges</td><td rowspan="4">AND/OR</td><td rowspan="2">Sustainable development</td></tr>
<tr><td>Urban design</td><td>Problems</td></tr>
<tr><td>Urban form</td><td>Solutions</td><td rowspan="2">Sustainability</td></tr>
<tr><td>Urban development</td><td>Opportunities</td></tr>
</table>

### 2.2.3 Study selection criteria

If there are too many research records to choose from, then the search can be reduced using the terms (i) Developing countries, (ii) Sub-Saharan Africa, and (iii) South Africa. Articles on these topics were included, if they were published between 1 January 2013 and 31 March 2019. This is because Rio+20 was held from 20 to 22 June 2012. Rio+20 was the biggest UN conference ever presented; the previous Earth Summit had been held 10 years earlier. Therefore, it was decided only to include articles that had been published the year following this event, if they were relevant to sustainable urban planning. See

Figure 2.2, which displays the number of documents published per year from the relevant research papers produced over the last ten years.

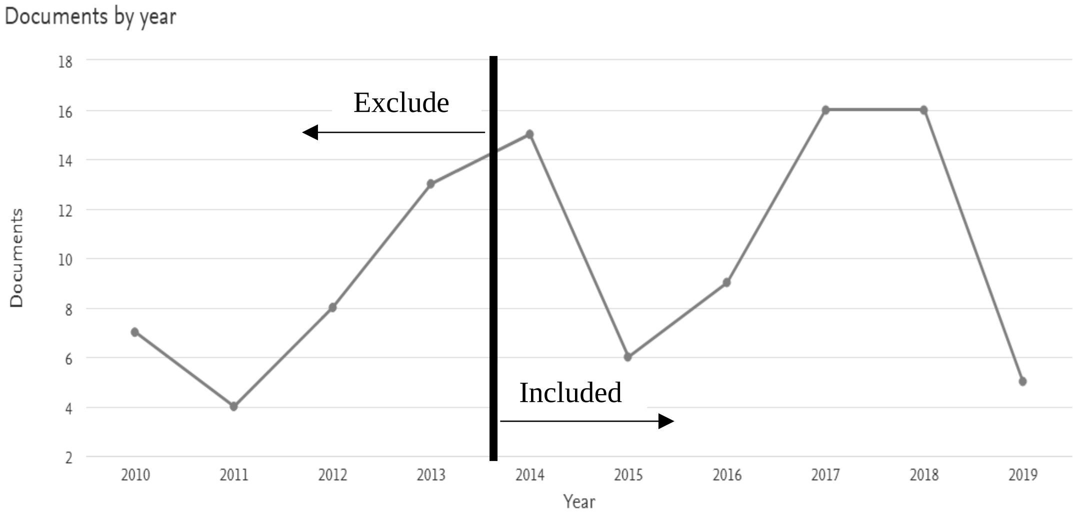



*Figure 2.2: Number of documents published per year - (line of exclusion)*

The following types of papers were excluded:

i. Informal literature surveys (no references, no publication);
ii. Papers not subject to peer-review; and
iii. Older versions of multiple papers found in more than one journal

Figure 2.3 is an illustration of the SLR search flowchart, which shows when and why papers were excluded, and the number of papers at each step of exclusion (Moher *et al.*, 2009). Of the original 783 documents that had been identified in the initial search, only 41 were found to be relevant to this particular study.

### 2.2.4 Data extraction strategy

The following data were extracted from each paper:

i. The name(s) of the author(s);
ii. The year when the paper was published. (Note that, if the paper was published in several different sources, all dates were recorded, and the earliest date was used in the analysis); and
iii. Every challenge mentioned in each paper relating to sustainable urban planning.

The identified challenges are referred to as a ‘topic’. Main topics contained several subtopics, which contributed to and connected to each challenge.

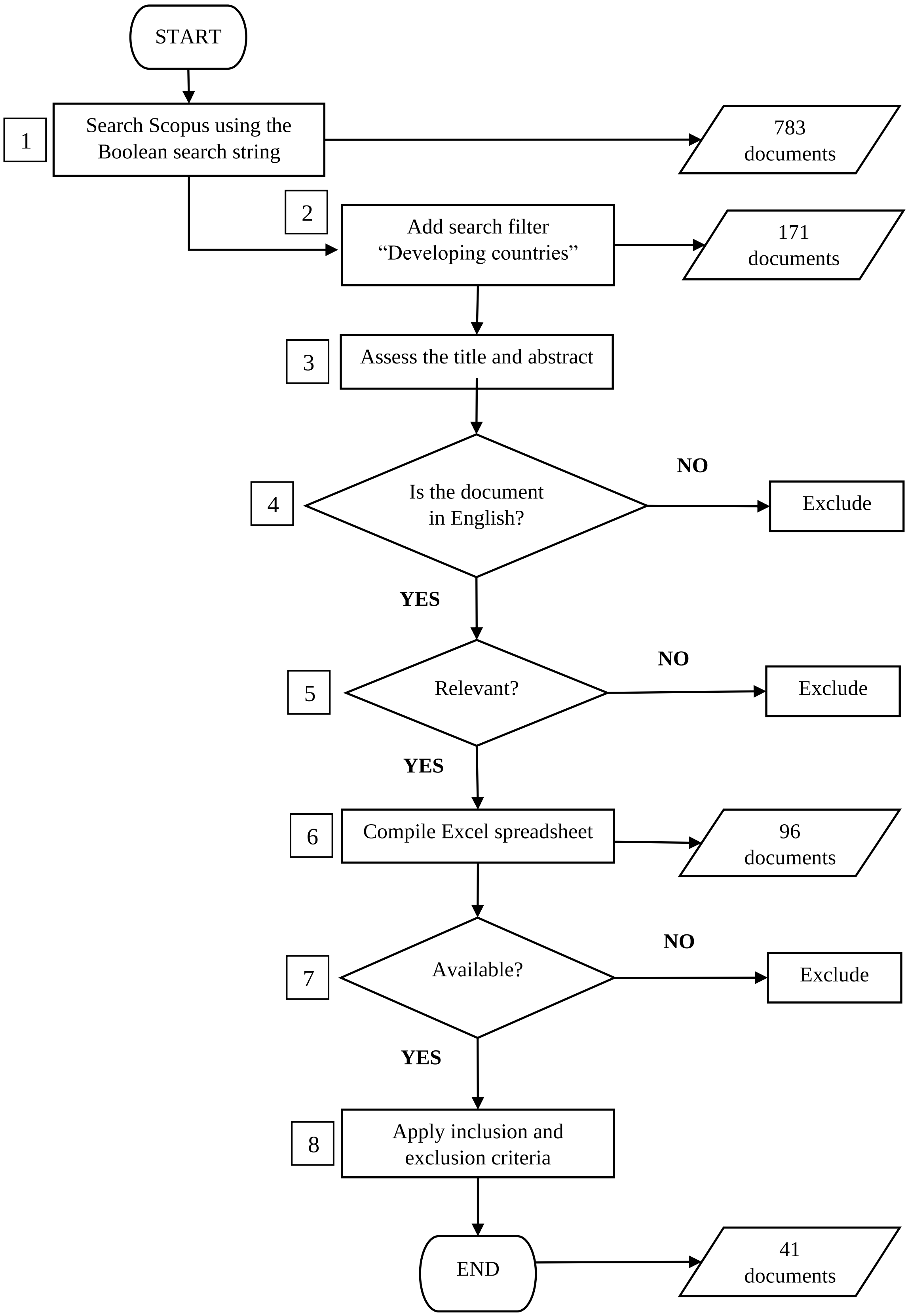



*Figure 2.3: Search flowchart*

The topics are as follows: (i) sustainability, (ii) planning, (iii) urbanisation, (iv) urban sprawl, (v) society, (vi) environmental, (vii) economic, (viii) developing country, (ix) population growth, (x) government, (xi) energy, (xii) food security, and (xiii) climate change. These topics were found to be the prevalent in the 41 research papers that dealt with sustainable urban planning.

### 2.2.5 Synthesis of extracted data

The sources were presented in a matrix (found in Appendix A.2), following the steps in Section 2.5 below; the number of articles within each topic and subtopic was added up. Thereafter, a synthesis of the most discussed topics was drawn up.

The next section looks at the bibliometric analysis found in the SLR, to gain deeper insight into the topic of sustainable urban planning in developing countries. There needs to be a connection to the urban system, so the different factors that express the urban setting must be a criterion for evaluation. The SDGs, for instance, are necessary to establish a sustainable criterion for evaluation. Moreover, urban system elements and SDGs are defined and categorised into the top three unbiased urban planning challenges, which will be identified in Section 2.4. Thereafter, the applied knowledge will be evaluated as part of the multi-criteria decision analysis (MCDA) in Chapter 4.

## 2.3 Bibliometric analysis

Additional information was gathered to enable a more detailed inquiry into the articles that were identified using the SLR. Referred to as a bibliometric analysis, this captured the location of where the corresponding author was geographically located versus where the study took place. The bibliometric study shows the comparison of where the research is produced, developing country versus developed country.

There are five different scenarios: (i) developed country producing research on a developed country, (ii) developed country producing research on a developing country, (iii) developing country producing research on a developed country, (iv) developing country producing research on a developing country and (v) developed or developing country producing general research on sustainable urban planning with no context. Scenarios (ii) and (iii) are illustrated in Figure 2.4 with arrows indicating the direction of the research, i.e., from where the research originated to the country under assessment.

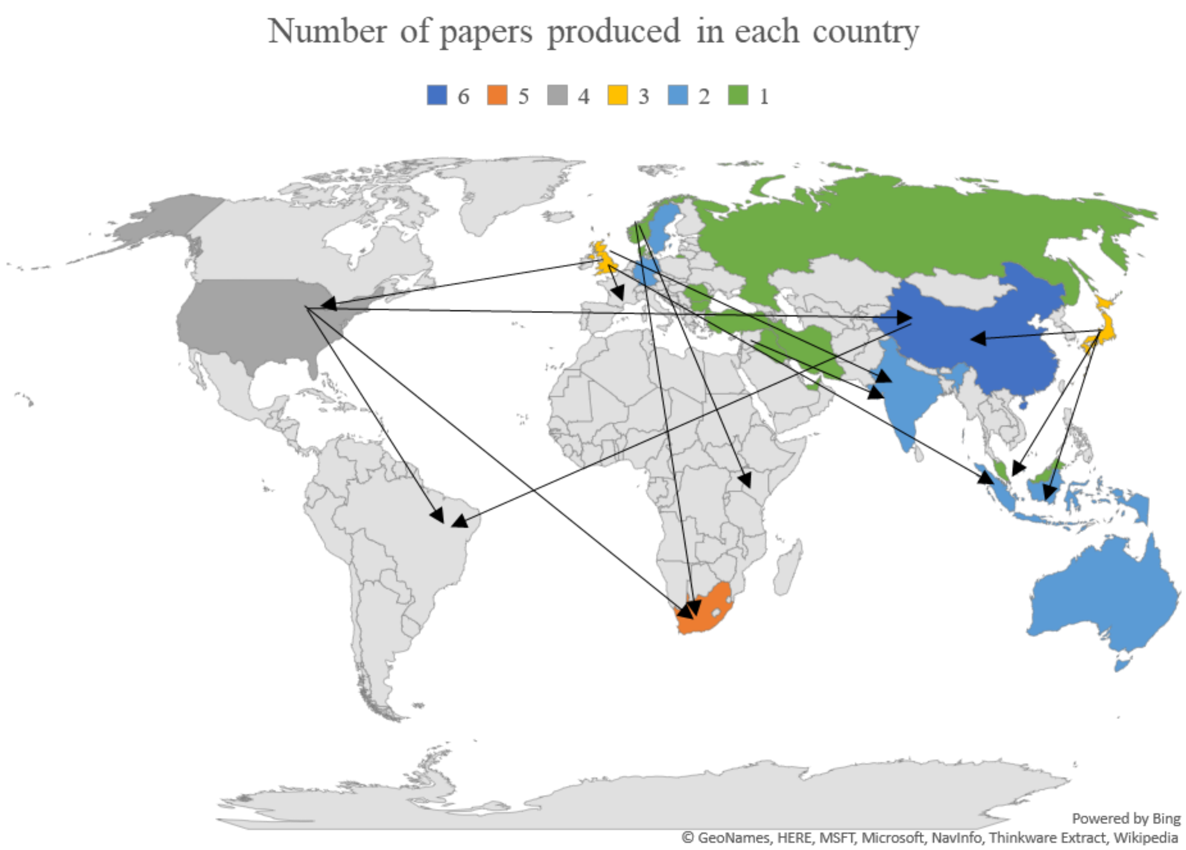



*Figure 2.4: Bibliometric world map*

The bibliometric study revealed nine studies that were of particular interest. These studies all fall under scenarios (ii) and (iii) above. A Swedish paper researched Kenya and South Africa. A study originating in Iraq inquired into India. Much of the research originated from the United States of America (USA), especially from the University of Illinois at Chicago; these were studies on China, Brazil, and Sub-Saharan countries. Japan studied Indonesia, China, and Thailand. A study from China looked at Brazil. Meanwhile, the United Kingdom conducted a comparative investigation into France, the USA, India and Singapore. These nine studies are only mentioned because these countries were conducting research in a foreign country.

## 2.4 Relevant challenges related to sustainable urban planning

With the use of a matrix, which contained all the challenges found in the 41 research papers selected in the SLR that related to sustainable urban planning, the prevalent challenges that pertain to the context of a developing country were chosen. These dominant challenges were then used to develop the links between current urban planning tools and techniques. This provided insight into the gap between the current planning practices relating to sustainability and the proposed future planning technique that was developed in this research project. In this section, the challenges identified by means of the SLR are discussed. As will be mentioned in Section 2.5 , the challenges fall under 13 important topics. From this list, six topics have more than 50 challenges, and they are summarised in Table 2.2. The sustainable urban planning challenges landscape can be found in Appendix A.1.

*Table 2.2: Six main topics covered by the systematic literature review (SLR)*

| Main topic | Primary + Secondary total | Primary total |
|---|---|---|
| Urban planning | 198 | 137 |
| Sustainability | 115 | 46 |
| Developing country | 90 | 55 |
| Urbanisation | 88 | 70 |
| Urban sprawl | 85 | 59 |
| Population growth | 50 | 38 |
| Totals | 626 | 405 |

The differences between the 'Primary + Secondary total' column and the 'Primary total' column are where these challenges appeared. The 'Primary total' was found only under the specific topic in question. However, the 'Primary + Secondary total' is where all the specific challenges were found throughout the matrix. For example, 'Primary + Secondary total' contained the challenges found under any topic. If a challenge was also associated with an economic and urban planning issue, it was considered to fall within the 'Primary + Secondary total' of economic and urban planning topics respectively.

There are 581 challenges in the SLR challenges matrix that were extracted from the 41 selected research articles. Furthermore, 34 per cent of these challenges were about planning, while 20 per cent were linked to sustainability. From Table 2.2, it is evident that the total of all the main topic challenges adds up to 626. This is because the matrix is set up in such a way that each topic area contains topics to which the challenge is linked. Take, for example, the challenge that states, "Identifying a sustainable form of growth, especially when considering specific local context and conditions is a difficult task. Implementation of plans and the realisation of urban forms are even more challenging" (Slaev and Nedovic-Budic, 2017). This challenge is about the combination of sustainability and urban planning. Thus, it was placed under the primary topic of sustainability and under the secondary topic of urban planning These finding were first presented for SAIIE at the 2019 conference (see Appendix B.1).

### 2.4.1 Challenges relating to urban planning

Out of 137 challenges from the SLR that are found in 'urban planning'; 19 relates to sustainability, 17 to society, and 10 to environment. The three prominent primary subtopics were found only in the topic of urban planning and not in the 'primary + secondary total', as seen in Table 2.2.

#### *2.4.1.1 Sustainability*

There is a lack of consensus on how to incorporate sustainable traditions into urban planning (Shummadtayar, Hokao and Iamtrakul, 2013; Mohareb, Derrible and Peiravian, 2016; Bibri, 2018; Grădinaru *et al.*, 2018). The challenges arise when trying to translate sustainability into city development. Planners have their own definitions and contexts that will disrupt any collaboration that might need to take place between policy coordinators, stakeholders, and government.

#### *2.4.1.2 Society*

Poor urban planning causes unwanted and spatially disjointed urban forms, leading to increased traffic congestion, vulnerability, and risks, and decreasing public health for the inhabitants in vulnerable areas (Kaagaard, 2016; Endo and Shibuya, 2017; Bibri, 2018; Moroke, Schoeman and Schoeman, 2019). Research reveals that planners do not realise the larger impact that their inconsistent planning practices have on social dynamics in communities.

#### *2.4.1.3 Environment*

Urban planners seem to have the right intentions to protect the environment through designing cities and buildings. However, this has led to contradictory outcomes, in which urban expansion has become unplanned, thus increasing carbon emissions and developing environmentally hazardous zones for residents (Wamsler, Brink and Rivera, 2013; Laffta and Al-Rawi, 2018; Shabatura, Bauer and Iatsevich, 2018). Unplanned urban expansion causes further distance to travel to work, more infrastructure to be built and built environments that do not meet structural safety codes. Urban planners need to take more responsibility for their impact on the environment.

### 2.4.2 Challenges relating to sustainability

Out of 46 challenges from the SLR that are found under ‘sustainability’; 11 relates to urban planning, 4 to resource management, and 4 to environment (which will be discussed in the subsections below). The three prominent primary subtopics were found only in the topic of sustainability and not “primary + secondary”, as seen in Table 2.2.

#### *2.4.2.1 Urban planning*

Sustainable urban planning is imperative in today’s city planning strategies. With the term having come into common usage one would think that there would be a set definition to which everyone would adhere. However, “there is no agreement of sustainable urban forms” (Habibi and Zebardast, 2016). The confusion has led to the term ‘sustainable urban planning’ becoming distorted and impractical (Kaagaard, 2016). Even if one were to agree on a sustainable urban form for a specific context, there would still be little support from policy-makers and government to enable the more consistent implementation of the practices (Russo, Alfredo and Fisher, 2014; Slaev and Nedovic-Budic, 2017).

#### *2.4.2.2 Resource management*

The essence of sustainability is to provide for future needs. A major concern is the depletion of natural resources, such as energy, water, and food. “Natural resources should be seen as capital and not an income source” (Randhawa and Kumar, 2017). Critical analysis should be done to understand the current stock levels of a city’s resources, and cities should venture to become a more self-sufficient system via circulation of reusing resources, and limiting human activities (Chang and Sheppard, 2013; Currie and Musango, 2017; Grădinaru *et al.*, 2018).

#### *2.4.2.3 Environment*

Environmental conservation is rarely implemented in a nation's policies, as it is commonly seen as anti-development, especially in developing countries, whose main goal is to be economically active and prosperous (Russo, Alfredo and Fisher, 2014; Kaagaard, 2016; Battersby, 2017).

### 2.4.3 Challenges relating to developing countries

Out of 55 challenges, from the SLR that are found in 'developing countries'; 6 relates to economy, 6 to society, and 5 to urban planning. The three prominent primary subtopics were found only in the topic of developing country and not "primary + secondary", as seen in Table 2.2.

#### *2.4.3.1 Economy*

Due to economic constraints, developing countries face many challenges when it comes to implementing sustainable urban planning practices (Wamsler, Brink and Rivera, 2013; Russo, Alfredo and Fisher, 2014; Ding *et al.*, 2015; Bai *et al.*, 2017; Battersby, 2017). Whether projects are aligned with transport, water security, or enabling technological assistance, developing countries are falling further behind in applying sustainable principles to these projects.

#### *2.4.3.2 Society*

Developing countries face great challenges in the realm of social sustainability. A general definition of a developing country is one that is plagued with inequalities of income and quality of life, in which residents experience underemployment, inadequate shelter, and poor living environments (Chang and Sheppard, 2013; Simon, 2013; Bai *et al.*, 2017). This is coupled with political systems that are based on the mistaken belief that all development is good if it provides jobs (Battersby, 2017). However, such a belief is not based on sustainable practices: it is one-sided in following a strictly economic path without taking into account the public's concerns for their society's wellbeing.

#### *2.4.3.3 Urban planning*

Urban planning in low- to middle-income countries cannot follow the development trends of developed countries due to the deep-rooted influences of uneven development that are a heritage of colonialism (Horn, 2015). Furthermore, even if developing countries do want to produce sustainable urban forms, they often lack the infrastructure and management capabilities (Babalik-Sutcliffe, 2013; Wamsler, Brink and Rivera, 2013).

### 2.4.4 Challenges relating to urbanisation

Out of 70 challenges from the SLR that are found in 'urbanisation'; 14 relates to sustainability, 10 to society, and 9 to developing country. The three prominent primary subtopics were found only in the topic of urbanisation and not "primary + secondary", as seen in Table 2.2.

In this section, the urbanisation phenomenon of urbanisation is briefly examined before developing the connection to urban system elements and SDGs. Urbanisation consumes extensive natural resources, which challenges the ideal of sustainability, and furthermore produces heat-island effects and compounds environmental and social problems (Chang and Sheppard, 2013). Problems with infrastructure services and utilities, traffic congestions, pollution and a reduction in natural green vegetation cover all arise from rapid urbanisation (Randhawa and Kumar, 2017). Serious environmental and social problems occur when the negative impacts of urbanisation are overlooked or actively ignored due to a technocratic bias among governments and policy-makers (Shabatura, Bauer and Iatsevich, 2018).

Urbanisation is full of paradoxes; having a large percentage of a country's population living and working in urban environments (Randhawa and Kumar, 2017) or migrating to cities in search of improved living situations (Larasati, Handayaningsih and Sumarsono, 2019) also has an adverse effect on the health of people, causing physical and mental fatigue and triggering a disorder of the nervous system (Shabatura, Bauer and Iatsevich, 2018). This is more evident in low-income cities where urban expansion threatens the resource base and the service delivery capacity (Broto, 2017). "Urbanisation determines both the quantity and fuel option (coal, oil, natural gas, etc) consumed in developing countries" (Musango, 2014).

#### *2.4.4.1 Sustainability*

Rapid urbanisation is also associated with other major issues, such as resource consumption, environmental damage, economic and political changes, along with social problems; and so it is unsustainable in respect of urban planning (Chang and Sheppard, 2013; Wamsler, Brink and Rivera, 2013; Zhang, 2016; Brelsford *et al.*, 2017; Randhawa and Kumar, 2017; Bibri, 2018; Shabatura, Bauer and Iatsevich, 2018).

#### *2.4.4.2 Society*

Urbanisation causes significant disruptions from the perspective of social sustainability, producing social segregation, higher levels of pollution, unequal distribution of wealth, and poor public health systems (Musango, 2014; Randhawa and Kumar, 2017; Xu *et al.*, 2017; Shabatura, Bauer and Iatsevich, 2018; Moroke, Schoeman and Schoeman, 2019).

#### *2.4.4.3 Developing country*

Urbanisation has a significant impact on developing countries, creating unplanned urban development, changing economy-oriented priorities for governments, threatening resource bases, and dictating fuel consumption patterns (Musango, 2014; Brelsford *et al.*, 2017; Broto, 2017; Currie and Musango, 2017; Randhawa and Kumar, 2017).

### 2.4.5 Challenges relating to urban sprawl

Out of 59 challenges from the SLR that are found in 'urban sprawl'; 11 relates to transportation, 10 to urban planning, and 9 to society. The three prominent primary subtopics were found only in the topic of urban sprawl and not "primary + secondary", as seen in Table 2.2.

As a low-density and dispersed form of urban expansion, sprawl poses a risk to sustainability. Characterised by the overdevelopment of infrastructure along the edges of cities, it also causes a dependency on cars, unless there is a strong presence of public transport options (Slaev and Nedovic-Budic, 2017). There are also paradoxes regarding eco-cites and sprawl. Eco-advocates' concern for urban ecology is generally associated with anti-growth politics. However, eco-cities capitalize on their natural ecology to promote urban growth, which may undermine these same ecological conditions: "*entrepreneurialism constructs nature only to promote its destruction*" (Prytherch, 2002, p. 787).

Therefore, when following eco-city planning methods an emphasis needs to be made regarding urban growth principles and the negatives urban sprawl.

"*Preservation of agricultural land can be affected by unsustainable relationships with settlements' development, which is a lack of long-term planning and policy objectives leading to a large decline in arable land due to unplanned informal settlements*" (Grădinaru *et al.*, 2018, p. 63).

The economic viability of a neighbourhood is negatively affected if there are no planned services, like clinics, playgrounds, and parks; this is worse if there is a low population density (Ahmed, 2017).

Greenbelts were originally used as the first line of defence against urban sprawl. Nowadays, however, greenbelts encourage leapfrog development, by acting as land reserves for future highways, and thus creating even longer distances between the inner city and the outskirts (Horn, 2015).

#### *2.4.5.1 Transportation*

Transportation is heavily affected by urban sprawl. Most of the jobs in cities are located in the city centre. So, when cheap residential development occurs on the outskirt commuters need to travel further, which produces more harmful emissions per person in the city. "*Sprawl, as a low-density and dispersed form of urban expansion, is generally considered to be a threat to sustainability: it is characterised by inefficient modes of transit*" (Slaev and Nedovic-Budic, 2017, p. 1). Sprawling development patterns cause car-dependent societies: people are forced to travel long distances, spending up to 40 per cent of their income on transport to their places of employment in town (Simon, 2013; Dur, Yigitcanlar and Bunker, 2014; Ahmed, 2017; Artmann *et al.*, 2019; Moroke, Schoeman and Schoeman, 2019), thus further increasing carbon emissions and contributing to climate change.

#### *2.4.5.2 Urban planning*

Urban sprawl is a major problem for urban planners. It exists due to inadequate decision-making and management systems (Bibri, 2018), leading to concerns about the availability of arable land for future generations' food security (Aburas *et al.*, 2018; Grădinaru *et al.*, 2018).

#### *2.4.5.3 Society*

Urban sprawl also disrupts the social environments of communities on the peripheries of cities, reducing public health due to commuters having on average 2 hours in traffic, and increasing social segregation (Shummadtayar, Hokao and Iamtrakul, 2013; Kaagaard, 2016; Slaev and Nedovic-Budic, 2017; Bibri, 2018). Spending so many hours in traffic is not good for mental health and physical health as people don't have enough time in the day to exercise as they spend so long to travel to work.

### 2.4.6 Challenges relating to population growth

Out of 38 challenges from the SLR relating to 'population growth'; 10 relates to developing country and 5 to urban planning. The two prominent primary subtopics were found only in the topic of population growth and not "primary + secondary", as seen in Table 2.2.

"*The worldwide urban population is estimated to be 3.3 billion and is predicted to almost double by 2050. The speed and scale of this growth is concentrated in developing countries*" (Shummadtayar, Hokao and Iamtrakul, 2013, p. 45). Urban planners have an opportunity to make a positive impact on this situation. Because if they don't do anything, cities can be overrun with food scarcity, resource deficit, etc. "*The challenges related to rapidly growing urban populations include meeting a massive need for urban infrastructure and protecting the urban environment*" (Zhang, 2016, p. 425).

Climate change has increased food insecurity and malnourishment of populations around the world, but especially in developing countries. In 2016, data showed that more than 25% of 815 million undernourished people live in Africa, and this statistic is expected to worsen (Tutu and Busingye, 2018). The urban population in developing countries is increasing much more rapidly than in the rest of the world, causing an expansion of economic, social and environmental problems within cities (Horn, 2015).

Although developed countries are experiencing a better provision of health services and a wider availability of health care, these countries are not free from problems; an emerging issue is the provision of specialised elderly care to the aging population, which requires the attention of trained specialists. Moreover, developed countries also need to accommodate a large and growing older population that will retire and need government assistance in the form of pensions, either state or private pensions. If the aging population is not taken care of in developed countries, the economy would lose an opportunity to create jobs and increase quality of life. If nothing is done the social-economic development of the country may be impaired in some way (Chaparro and Kulkarni, 2015).

The challenges faced by developing countries, in contrast, are driven by the large youthful population. Education and job creation thus need to be prioritised in these countries. Doing so will create benefits for the economic and environmental stability of the city. Refer to the explanation of Figure 2.5 regarding the different economies to scale and how they play their part with regard to job opportunities in either the private or public domain.

#### *2.4.6.1 Developing country*

Worldwide population growth in future decades will be concentrated in developing countries (Shummadtayar, Hokao and Iamtrakul, 2013; Russo, Alfredo and Fisher, 2014; Horn, 2015; Endo and Shibuya, 2017; Aburas *et al.*, 2018; Moroke, Schoeman and Schoeman, 2019).

#### *2.4.6.2 Urban planning*

Given the unprecedented population growth occurring all over the globe, urban planners are struggling to keep up with all the infrastructural needs (Ding *et al.*, 2015; Mohareb, Derrible and Peiravian, 2016; Zhang, 2016; Li *et al.*, 2019).

## 2.5 Grouping prevalent sustainable urban planning challenges

Table 2.2 above identifies the six most discussed topics that were found in the SLR, namely: urban planning, sustainability, developing country, urbanisation, urban sprawl and population group. Each of these topics was discussed in the previous sections.

The topics that coincide with the search criteria are urban planning, sustainability, and developing country; these are particularly relevant to this research. All the challenges looked at in this study were drawn from 32 research papers. The search found nine papers that described challenges that the majority were not discussing. This is not to say that the other nine papers were not considered, but they focused primarily on solutions. The topics that are of particular importance for this thesis, based on the SLR, are urbanisation, urban sprawl, and population growth. It is evident that these three phenomena are all dependent on one another. For example, population growth leads to urbanisation, as people need to gain money and thus migrate to the cities, which have more services and resources. This combination leads to rapid expansion of cities, causing urban sprawl, along with all its negative impacts. To mitigate the problems caused by urban sprawl, urban planners need to resist the anti-development agenda. Adaptation methods and techniques must first be incorporated by urban planners to manage the current issues with urbanisation. Then the new plans must develop a resilient structure to combat these challenges as they arise. It is more important than ever for urban planners to use technology to predict rapidly changing trends and to enhance the sustainability of cities in developing countries. It is also known that developing countries lack data and specialised personnel. Hopefully, this research will lay the foundation for incorporating the latest effective technology. The sustainable urban planning challenges can be found in Appendix A.1.

To identify the connections between the challenges faced by urban systems, the various elements require clarification. Also, in order to link the challenges to the SDGs, it is necessary to understand these goals. The three challenges will be further discussed in terms of two new specifications, namely, urban system elements and SDGs. The new specifications relating to these will be the criteria to be applied to the tools and techniques that will be identified in Chapter 3. Thereafter, a MCDA will be used to evaluate the urban system elements and SDGs in order to create requirements specification in Chapter 4.

### 2.5.1 Urban system elements

In order to define what is meant by a city, one needs to understand the elements and complex interactions between the elements in an urban system. The urban setting can be represented as different features and aspects, which can be qualified into elements (Dempsey *et al.*, 2010). The urban system elements, as well as their brief descriptions and a list of features and aspects representing each element, are listed in Table 2.3.

*Table 2.3: Urban system elements. Source: (Dempsey et al., 2010)*

| Element | Description | Feature/Aspect |
|---|---|---|
| Residential | Residential and communal accommodation | Ordinary accommodation, care homes and university residences |
| Commercial | Properties for commercial and retail purpose | Supermarkets, shops, storage, warehouses and restaurants |
| Business | Office space | Business parks, banks and companies |
| Industrial | Properties for industrial purposes | Factories, workshops, and industrial storage facilities |
| Community | Properties for community purposes | Educational, health and government services |
| Recreational | Properties for recreational and leisure purpose | Museums, libraries, cinemas and sport activities |
| Biophysical assets | Spaces of grassland and woodland | Biodiversity and agriculture |
| Infrastructure | Components that allow the city to function | Water, electricity and land resources |
| Transport network | Links between the different areas of a city | Roads, bridges and fuel resources |
| Socio-economic activities | Agents interacting with the city system | People |

Table 2.3 above listed the different elements that make up a city system (Dempsey *et al.*, 2010). In terms of economic activity in the system, the commercial, business and industrial elements describe the micro, meso and macro levels of economic activity, respectively. Refer to Figure 2.5 for an illustration of the interaction of these three levels.

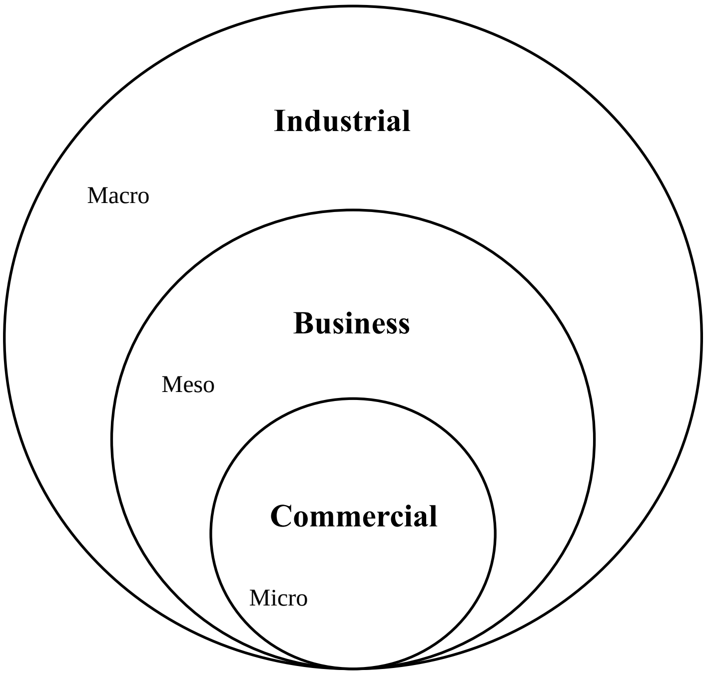



*Figure 2.5: Economies to scale for the city elements*

The diagram in Figure 2.5 also indicates how many resources (in the form of energy, water, land and fuel) are required within each element or within each level. There is a direct association to how much gross domestic product (GDP) is generated due to the amount of resources used at each level in the economy. However, the number of job opportunities relating to each sector, commercial, business, industrial, may not correlate to the actual economic benefits for people within cities, because some of these sectors may be more sustainable for a city than for the country as a whole. In other words, economic gains from industrial plants or factories may generate more GDP for a country as a whole, but not provide enough jobs to sustain the people in the city in which they are located. Therefore, the small to medium enterprises in a city, which may not generate much GDP for the country as a whole, may in fact be more important to a particular city because they provide jobs to the residents and thus increase the economic and social stability of a city. These justifications will be quantified within the pairwise comparisons in Section 4.3.

### 2.5.2 Sustainable development goals

Defining the elements of the city system allowed us to look at the urban planning point of view. Next, the sustainability aspect should be further defined. The most universal and recognised definitions of sustainability are the 17 sustainable development goals (SDGs) established by the United Nations (UN) in 2015. Figure 2.6 illustrates the 17 SDG, which countries around the world agreed to adhere to in order to accomplish them by 2030. The SDGs were developed alongside an agreement among all the countries of the UN to reduce their carbon emissions so that the global temperature does not increase by more than two degrees Celsius by 2050.


*Figure 2.6: The Sustainable Development Goals (SDGs). Source: (United Nations (Habitat III), 2017)*

The urban systems elements and the SDGs are used to quantify the urban planning challenges for an analytical hierarchy process (AHP) using a pairwise comparison, followed by the least square method (LSM) for normalisation.

## 2.6 Linkages between identified sustainable urban planning challenges and sustainable development goals

The challenges of sustainable urban planning are defined in the following subsections using the SLR. Using this information along with the elements defined in Table 2.3 (Dempsey *et al.*, 2010), the connections between the challenges that affect the city system can be assessed in greater depth.

### 2.6.1 Elements of urbanisation

Urbanisation refers to the phenomenon where people migrate from the rural regions to the urban regions of a country. There are many reasons why people choose to migrate to the city. Many seek the increased probability of finding a higher paying job. Some travel far for a job to get more money just to send it back home to sustain the family members who remain in the rural areas. The majority need to find cheap accommodation, often far outside of the city, where the job is located, and thus need to travel long distances, often using unreliable public transport to reach the destination in the city. This creates a challenge for urban planners to create jobs in the locations where the workforce actually resides, and to create accommodation where the jobs are located. Furthermore, low-income earners spend close to 40% of their income on transport to and from the job, leaving very little money for rent, food and other necessities. Moreover, they still need to send money back to the families back home in the rural parts of the country.

The short summary of the challenges associated with urbanisation need to be defined, with regard to the elements that affect the city system. It is important to note how they are selected by the author. Each urban planning challenge needs to have a direct effect on the element that is associated with it. Indirect connections will not be chosen to represent the challenge to the city system elements. For example, urbanisation does not directly affect biophysical assets, because this refers to a migration of people from rural to urban settings. However, eventually there may be less people working in the agricultural sector to provide for food security for the larger population, which has been gathered in the city.

*Table 2.4: Elements of urbanisation*

| Element | Description |
|---|---|
| Residential | The location and cost of accommodation are important details for this selection. The ideal would be for accommodation to be cheap and closest to the job opportunity. |
| Commercial | The location and salary of the job opportunity would be an important detail to influence this selection. |
| Industrial | The location and salary of the job opportunity would be an important detail to influence this decision. |
| Transport network | This includes the type of transport used: train, bus, car or bike, with the cheapest or easiest option being the preferred one. |
| Socio-economic activities | People who move to the cities for economic benefits need to change their lifestyle to meet their main goal, which is to provide income for their families who remain in the rural areas. Therefore, they may not take good enough care of themselves and lead unhealthy lives, by not meeting their needs for good food and healthy living, in order to reduce their expenses. |

### 2.6.2 Sustainable development goals relating to urbanisation

Which of the SDGs are addressed in relation to urbanisation? It is important to note how they are selected to define according to the SDG. The urban planning challenge needs to directly affect the element that is associated with it. Indirect connections will not be chosen to represent the challenge to the city system elements. [For example, the quality education goal may not directly affect urbanisation. However, when it comes to specific skill training or when an entire family with kids migrates to a city, then the increased capacity of education services is an important criterion.

*Table 2.5: SDGs relating to urbanisation*

| # | SDG | Description |
|---|---|---|
| 1 | No poverty | Most occurrences of urbanisation result from rural to urban migration, due to families needing more financial stability by seeking opportunities in the city. |
| 6 | Clean water and sanitation | The right to clean water is universal. When moving to unknown and potentially precarious settlements, access to water is not always a certainty. |
| 7 | Affordable and clean energy | The right to affordable energy should be universal. When moving to unknown and potentially precarious settlements, safe access to electricity is not always a certainty. |
| 8 | Decent work and economic growth | The driving force of urbanisation is the premise of job opportunities that the city offers. |
| 9 | Industry, innovation and infrastructure | Urbanisation needs help from industry by providing opportunities, innovative ideas to progress as a community and a stable infrastructure to maintain the growing migration into the city. |
| 10 | Reduced inequalities | Equal opportunities must be assured for all job seekers. |
| 11 | Sustainable cities and communities | The informal urban settlements need to withstand the test of time. Sustainability is also about ensuring there is enough resources and structure till the next generation. Service provision and capacity should meet the demands of the population. |
| 12 | Responsible consumption and production | Resources should be available for everyone, and wastage of any resource needs to be reduced. |

### 2.6.3 Elements of urban sprawl

In an attempt to solve some of the challenges that urban planners face, the easiest solution is often to build on the edges of cities. This is certainly a viable option, but it is one that runs into many problems. Stretching further out from a city to build more accommodation requires more infrastructure, like electricity pylons, water and sewage pipes, as well as roads and railway networks to connect people to the rest of the city. If the service capacity is not increased, such as education, healthcare and public transport, people will need own cars to travel longer distances. Carbon emissions will be increased through the construction of new buildings and the increased use of private cars, unless public transport is made available too. Zoning codes within cities are very outdated and need to be revaluated, because these codes discourage inner-city construction of necessary building types that are more sustainable. Furthermore, projects within cities need to develop multi-purpose zones to account for the increased number of people, services and infrastructure that would occur if urban sprawl continues.

The challenges associated with urban sprawl need to be defined in relation to the elements that affect the city system. It is important to note how they have been selected by the author. The urban planning challenge needs to directly affect the element that is associated with it. Indirect connections will thus not be chosen to represent the challenge to the city system elements. For example, urban sprawl generally occurs due to people needing accommodation in the cities; urban sprawl is rarely related to a need to a land for industrial use. However, eventually the land would have been more useful for industrial purposes because of the distance from the city. Consequently, what adds to the problems are informal settlements popping up on the edge of cities, taking over land that could've been used for industry.

*Table 2.6: Elements of urban sprawl*

| Element | Description |
|---|---|
| Residential | It is important to reduce the distances between new residential developments and job locations. |
| Business | The location of new business areas needs to take the urban sprawl phenomenon into account. The further an employee needs to drive to the business area, the worse the negative effect of urban sprawl. |
| Community | Services like public transport, health and education need to keep up with the demand of housing development. |
| Biophysical assets | Urban sprawl eats away at the surrounding land, which could otherwise be used for agriculture outside of cities. In addition to decreasing the total available for farmland, urban sprawl also increases the distance that food needs to travel from the outskirts into the city centres. |
| Infrastructure | Urban sprawl on the fringes of cities means that more infrastructure (sewers, electricity, roads, etc.) is required to connect these areas to the rest of the city. |
| Transport network | Urban sprawl increases the distance that residents on the outskirts need to travel in order to access necessary services and jobs. It furthermore increases dependency on private cars, which is bad for the environment. |
| Socio-economic activities | Urban sprawl encourages people to reside in a cheaper house outside the city. But then they must commute for hours each day to reach their jobs in the city which increase the carbon emissions and negates any savings from purchasing cheaper housing due to an increase in fuel spending. |

### 2.6.4 Sustainable development goals relating to urban sprawl

Which of the SDGs relate to urban sprawl? It is important to note how they are selected by the author. The urban planning challenge needs to directly affect the element that is associated with it. Indirect connections will not be chosen to represent the challenge to the city system elements. For example, urban sprawl does not have a direct relation to the SDG relating to poverty. Urban sprawl refers to the continuous construction of mostly residential areas on the outskirts of a city. It may not relate to either suppressing or uplifting the economic status of people in those areas in the short term or long term.

*Table 2.7: SDGs relating to urban sprawl*

| # | SDG | Description |
|---|---|---|
| 2 | Zero hunger | Land on the edge of cities is constantly used for more unnecessary development, such as unplanned or informal settlements on the outskirts of cities. Reducing the total area that could be potentially available for farmland. |
| 3 | Good health and well-being | A car dependant lifestyle is very unhealthy. However, due to the distances between their homes and their places of work and available services, people tend to spend hours driving each day, which also reduces their time and opportunity to be active and thus improve their health. |
| 6 | Clean water and sanitation | Urban sprawl refers to continuous development on the edges of cities. It means that more infrastructure is needed to provide the people on the outskirts with safe and clean water for drinking and sanitation. |
| 7 | Affordable and clean energy | More infrastructure is needed to provide the people on the outskirts with affordable and safe energy. |
| 9 | Industry, innovation and infrastructure | The consistent increase in infrastructure such as sewers and electricity connections on the edges of cities is not a sustainable practice. |
| 11 | Sustainable cities and communities | There needs to be a balance when it comes to new construction projects. If there is a new residential project, then providing recreational, community and public transport services should be a top priority. Otherwise an unstable car-orientated culture is formed. |
| 12 | Responsible consumption and production | Continuously constructing residential areas on the outskirts of cities causes a perpetual loop of resource consumption for infrastructure development. This unstable habit is easy for city planners but not suitable for the long-term productivity of the city. |

### 2.6.5 Elements of population growth

Population growth may not seem like a new challenge for urban planners. Research suggests that developing countries are facing the greatest growth in population ever seen in human existence. By 2050, the urban population worldwide will increase from 58% to 70%, two-thirds of which will be living in developing countries. This phenomenon is similar to urbanisation, but more general and more closely associated with the long-term increase in birth rates and decrease in mortality rates. The number of megacities, which are cities with more that 10 million inhabitants, will triple all over the world. That leaves urban planners with the challenge to design cities that are able to accommodate more people, while increasing service capacity and leaving enough space for food production to feed the increased number of people.

The short summary of the challenges associated with population growth need to be defined in terms of the elements that that affect the city system. It is important note how these are chosen. The urban planning challenge needs to directly affect the element that is associated with it. Indirect connections will not be chosen to represent the challenge to the city system elements. For example, transport networks would eventually affect a large population within a city. However, the large number of people in the city will first have to have their needs met, which includes accommodation, food and water, before increasing the capacity of the transport network.

*Table 2.8: Elements of population growth*

| Element | Description |
|---|---|
| Residential | the amount of space that is needed to accommodate for the upcoming increase of people requires long term planning. |
| Community | increase of people should equate to service capacity such as education and health care to care for more people. |
| Biophysical assets | the increase in people means more people to feed. The space available for food production is paramount to sustain a growing city. |
| Infrastructure | more people will need electricity, water and other resources supplied. Referring to a large increase in capacity and maintenance to accompany the changes to the city system. |
| Socio-economic activities | this can mean opportunity. If these cities can keep up with the influx of people through accommodation, service capacity and food supply, the supply of people can increase economic activity. |

### 2.6.6 Sustainable development goals relating to population growth

Which of the SDGs are addressed? It is important to note how they are selected by the author. The urban planning challenge needs to directly affect the element that is associated with it. Indirect connections will not be chosen to represent the challenge to the city system elements. For example, climate action is not a direct relation to population growth. It would be unethical to reduce population growth in order to support a climate action agenda. It would be more important to teach the upcoming generations how to care for the planet and reduce their impact on nature and its resources.

*Table 2.9: SDGs relating to population growth*

| # | SDG | Description |
|---|---|---|
| 1 | No poverty | Most of the population growth that will occur in the upcoming decades will happen in developing countries, and in particular, among low-income groups. |
| 2 | Zero hunger | An increasing populace will need more food, as well as an increased capacity to meet the growing demand for food. |
| 3 | Good health and well-being | A highly populated area requires enough resources to allow each person to receive quality nourishment and quality health care to satisfy their needs. |
| 4 | Quality education | It is very important that the capacity of education services increases with the large number of children who are expected to be born in developing countries. |
| 8 | Decent work and economic growth | This goal is linked to job creation and the increasing pressure of unemployment in developing countries. |
| 10 | Reduced inequalities | There needs to be a fair chance for all residents within the city to achieve food, water and energy security without experiencing any discrimination or bias. |
| 11 | Sustainable cities and communities | The increasing numbers of new people who are anticipated to be born in developing countries will require more sustainable practices, which will ensure that their quality of life is not reduced due to the current generation’s actions or lack of actions. |
| 12 | Responsible consumption and production | Resource management will become more important in cities over the next few decades. The increasing population will need a greater amount of resources. Therefore, new ideas to generate, maintain, reuse and recycle these resources will become a priority. |

## 2.7 Conclusion: Chapter 2

The SLR research questions were formulated to ensure that the quality of the SLR was high. Firstly, what were the research topics addressed in the SLR? The SLR was framed around sustainable urban planning challenges in the context of developing countries. The topics that were identified in the SLR as most clearly challenging urban planners were urbanisation, urban sprawl, and population growth. These topics are interdependent and interlinked, and thus further investigation was needed to identify the crux of the problem they posed for sustainable practices in planning urban development.

Secondly, how effective was the SLR? By following the steps in the search flowchart (illustrated in Figure 2.3), the 783 research papers that had been identified originally were reduced to 41 research papers, which were found to be relevant for the SLR. All the challenges addressed in this study came from 32 research papers; the remaining nine papers described challenges that were not discussed by the majority of the papers. This is not to say that these nine challenges were not considered. However, for the purpose of the SLR, the goal was to identify the prominent challenges that have faced urban planners over the last seven years since Rio+20 in 2012. The SLR was 78 per cent effective in identifying most of the challenges.

Thirdly, it must be acknowledged that the SLR did have limitations and biases. The first limitation was the time frame, as it only considered research papers that had been published since 2013. This was because the Rio+20 conference was regarded as the defining event that influenced the subsequent research. Figure 2.2 assists this argument, showing a large increase in research produced from 2013 onwards. The bias in the study emanates from the specific search criteria (namely, urban planning, sustainability and developing country). The context of developing countries was a necessary focus for the study. Sustainable practices used in developed countries would be either too advanced or too expensive to allow developing nations to address their problems realistically.

The epistemology of pragmatism, which represented the philosophical approach used herein (see Section 1.4) states the importance of understanding the problems associated with the research (Saunders, Lewis and Thornhill, 2009). Therefore, the SLR focused on the current situation in the domain of sustainable urban planning, and looked at the challenges faced by urban planners when approaching sustainability in developing countries.

The five objectives were developed and achieved in this chapter. A Boolean search method was used to initiate the SLR. The challenges from all the relevant literature review papers were displayed with regard to the relevant topics, and the most frequently occurring challenges were identified and discussed. And lastly, the connection of the urban system elements and the SDGs to the challenges was identified and presented. The SLR will furthermore set out to uncover the tools and techniques used in current sustainable urban planning practices. Together with the synthesis in Section 2.5 , a more structured approach will be designed to help town planners to plan urban settings sustainably, in order to support future generations and enable them to be more balanced along the triple bottom line. Also known as the sustainability Venn-diagram of Figure 1.1.

Chapter 3 will focus on the tools and techniques found in the SLR using a content analysis. Thereafter, categorising and identifying the tools and techniques that are most likely to assist urban planners with implementing sustainable project.

# Chapter 3: Sustainable urban planning methods in developing countries

The objective of this chapter is to determine the best methods to increase the chance of successful transition to a more sustainable form of urban planning in developing countries, which is in line with objective RO2 as discussed in Chapter 1, Section 1.3. To achieve this, there are a few objectives that need to be met: (i) to investigate the tools and techniques that are currently used for urban planning, (ii) to categorise the tools and techniques that could assist in more sustainable urban planning decision making, and (iii) to identify the tools and techniques specific to sustainability practices that could be used in the requirements specification.

In accordance with the philosophy of pragmatism set out in Section1.4, it is necessary to investigate the practices associated with sustainable urban planning in developing countries. In this chapter, the tools and techniques that urban planners use to develop sustainable cities are thus identified and categorised. The 41 research papers that were analysed in the SLR in Chapter 1 were used to identify and gather the different tools and techniques. In this chapter, a content analysis was performed on the 236 tools and techniques that were found; thereafter, they were categorised. This categorisation followed a hierarchical structure, which led to tools and techniques being placed into groups established by the author; it was also discussed how and why these established groups were chosen. Thereafter, the tools and techniques underwent analysis to identify the major differences from one another. This analysis will be conducted in the multi-criteria decision analysis discussed in Chapter 4.

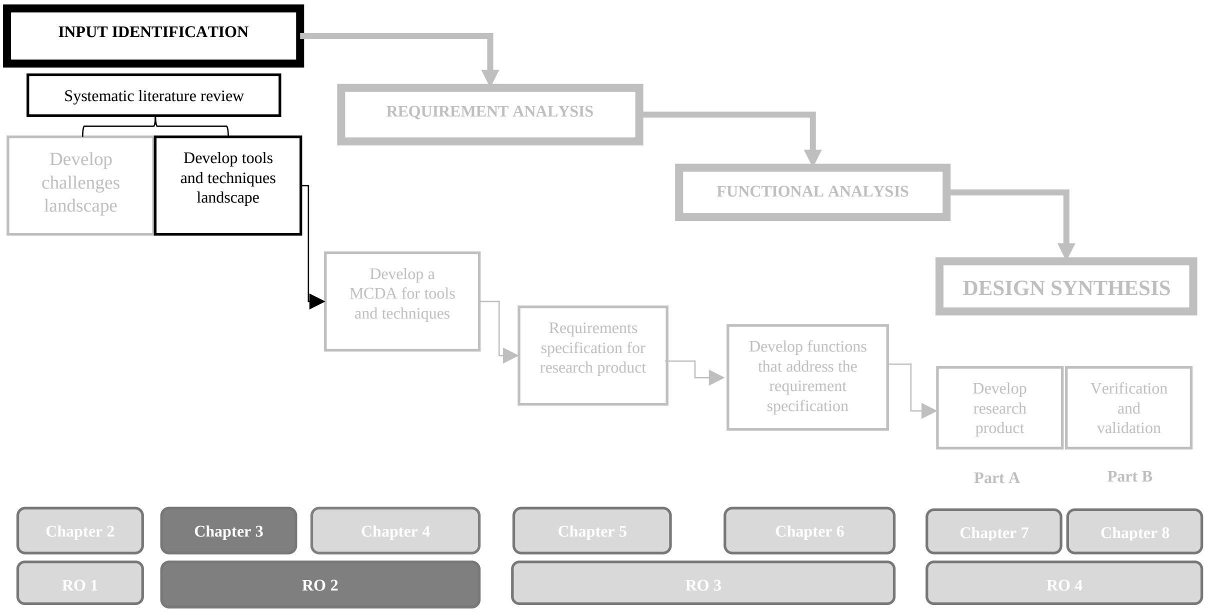



*Figure 3.1: Thesis schematic (Chapter 3)*

This chapter covers the categorisation criteria for identifying each of the tools and techniques found in the preceding SLR, and group these into five categories, namely: (i) paradigms, (ii) units of analysis, (iii) units of observation, (iv) qualitative or quantitative methods, and (v) types of approach. It is explained how and why these categories are chosen. The SLR is used to conduct a content analysis and develop a tools and techniques landscape (see Appendix A.2) that will be assessed further in the following chapters. This analysis covers the second research objective, namely determine the appropriate approach / method to support effective and efficient sustainable urban planning in developing countries.

## 3.1 Categorisation methodology

This chapter will be framed as a content analysis, which is a research method that bridges qualitative and quantitative content by means of a rigorous exploration of challenging topics of interest from the management of social issues to energy resource conservation (Duriau, Reger and Pfarrer, 2007). The first step is to define and group the topics found in the literature. The tools and techniques will be allocated to five categories: (i) unit of observation, (ii) paradigm, (iii) unit of analysis, (iv) qualitative vs quantitative, and (v) type of approach. Each of these categories is defined and explained in the subsequent sections of this chapter. Thereafter, in Chapter 4, the tools and techniques will be connected to the urban system elements and the SDGs by using these categorisations. In Chapter 4, an AHP study will be performed to form the unbiased quantifiable comparisons needed for the research product. The purpose of the tools and technique landscape was to reduce the large array of various tools and techniques studied in the reviewed literature into tools and techniques that are specific to sustainability and its implementation.

The categorisation hierarchy in Figure 3.2 illustrates the method used herein. The selection process flows from left to right, starting with 13 units of observations, which are then further classified into and related to five paradigms. Thereafter, these paradigms are looked at in terms of units of analysis (i.e., formal vs informal, urban vs rural). In the next step, it is evaluated whether the tool and technique was measured qualitatively or quantitatively, and lastly, the type of approach (e.g., generic, specific, solution orientated, or problem orientated) is considered. Thereafter, the tools and techniques undergo further analysis to uncover their connections to the challenges of sustainable urban planning.

A content analysis will lead to the initial stages of designing a research product, according to the overall aim of this study. The five different categories cited in the previous paragraph will help us to identify the different input parameters for the research product. In this regard, unit of analysis refers to the location or setting in which users are looking to initiate or implement their sustainable urban plan. The category of qualitative vs quantitative refers to the amount and type of available data that the users (primarily urban planners) need or that they can capture themselves. And finally, the type of approach is used to link the different tools and techniques into groups that indicate where they are situated along the problem-solving spectrum, which is illustrated in Figure 3.5 of Section 3.6.

## 3.2 Units of observation

Before continuing, it would be helpful to distinguish between the term ‘unit of observation’ and ‘unit of analysis’: “*Unit of observation is statistically defined as the ‘who’ or ‘what’ for which data are measured or collected, whereas unit of analysis is defined statistically as the ‘who’ or ‘what’ for which information and conclusions are made*” (P. Sedgwick, 2014, p. 8). It is important to note the differences between these two terms as they are mentioned throughout this chapter.

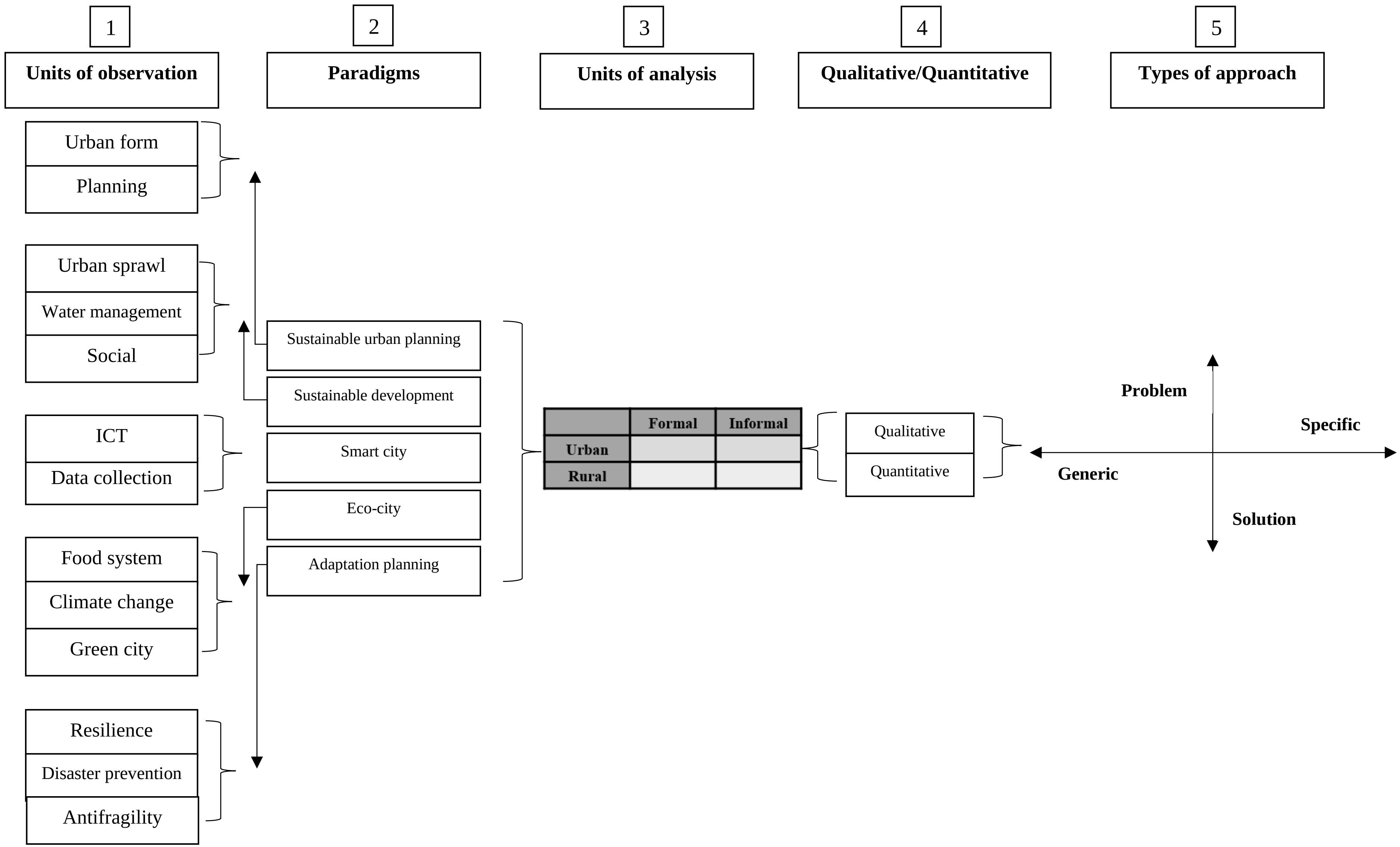



*Figure 3.2: Categorisation hierarchy*

Step 1 of the categorisation method is identifying the units of observation i.e. the methodology was as follows:

i. Gather all the tools and techniques mentioned in the 41 research papers found in the literature review;
ii. Identify what issues each tool and each technique attempt to resolve;
iii. Classify these ideas into groups; and
iv. Summarise these into 13 distinct groups.

Section 3.2.1 to 3.2.13 below describe the thirteen distinct units of observation with reference to the tools and techniques that could address or resolve the issues related to these. The tools and techniques landscape can be found in Appendix A.2.

### 3.2.1 Urban form

Polycentricity is a new way to combat urban sprawl. It is defined as follows: "Polycentric urban areas are compact yet separated – or, rather, connected – by large green areas and enclaves; thus, land resources are used economically, and urban and green environments are integrated. Polycentricity provides for economical use of land and savings in investment and energy" (Slaev and Nedovic-Budic, 2017).

This technique combines well with the corridor development techniques. These two techniques together motivate developers to concentrate their efforts in a couple of hubs within the borders of a city. Usually, these hubs comprise from the central business district and two or three additional areas of high economic activity. Corridor development is centred along the roads between these hubs.

### 3.2.2 Planning

Systems engineering is important for this study. It brings a methodology and structure to the planning and maintenance of the systems. "*Systems engineering support is applied for the development and testing of systems (energy, transport, traffic, etc.). Support can start in early phases and include topics like executable system architectures*" (Bibri, 2018, p. 773).

Coevolution is a new method in the built environment field. "*In an urban setting, coevolution referred to the coupling of social systems with particular configurations of the built environment that enabled resource transformation*" (Broto, 2017, p. 756). Merging social and infrastructural systems is important when designing cities. Coevolution assists in making resource management more efficient and more optimised toward the consumers.

Urban planning is specifically applicable to cities, whereas development is a broader concept. The major units of observations are urban sprawl, water management and social aspects. These three can be addressed both within a city and outside the city. To reiterate, sustainability is necessary to support the future generation, which should not need to face the same issues we face today. Therefore, it is important to develop and implement the practices that addressed the challenges of sustainable urban planning.

### 3.2.3 Urban sprawl

The use of green belts to separate cities from the surrounding areas came into practice after World War II: "*The green belt was part of the post-World War II package of English regional policies that were intended to protect farmland, to separate the major cities from surrounding settlements and to redistribute population*" (Horn, 2015, p. 132). This green belt initiative has not been successful in recent times to combat urban sprawl. According to the research, governmental organisations and larger corporations did not adhere to urban edge restrictions..

### 3.2.4 Water management

Greater efficiency with regard to water use by industries is a low-level method to improve water management in industry: "*Industrial water use efficiency was promoted by industrial centralization. Thus, industrial water use efficiency improvement was one of the basic strategies to solve urban water issues*" (Bai *et al.*, 2017, p. 2). It is especially important because industrial water usage in urban settings is high, and it is therefore important to measure and optimise its usage.

### 3.2.5 Social impacts

Social impacts are one of the three important aspects of sustainability (referring to environmental and economic aspects). Therefore, in developing countries, social impacts should also be studied and considered. There needs to be a balance between positive and negative outcomes in each domain of economic, environmental and social impacts in developmental endeavours, and decision makers should be held accountable for ensuring that all aspects are taken into consideration. "*The Southern African Development Community was an example of a progressive group regarding environmental sustainability. They maintained that poverty reduction did not need to compromise environmental health and services*" (Russo, Alfredo and Fisher, 2014, p. 3948).

### 3.2.6 Information and communication technology

In the context of tools and techniques and the units of observation, the use of information and communication technology (ICT) and data collection are the building blocks of developing a smart city. The tools and techniques comprised within this paradigm mostly aim to start the process of creating a smart city; they address the challenge of lack of data, and they connect city processes with the internet and enable the city and urban planners to solve problems more effectively by using new technologies, such as the internet of things (IoT), machine learning (ML), big data and artificial intelligence (AI). Within the smart city paradigm, the following examples of tools and techniques can be used to explain each unit of observation.

Information and communication technology (ICT) is an important unit of observation: "*ICT offers the government the possibility to be more transparent, accountable, using resources more effectively and empowering and educating citizens*" (Artmann *et al.*, 2019, p. 18). The government and the role of government is an optional aspect to include in sustainable development. Therefore, the tool of ICT in incorporating accountability and transparency within governmental activities is a very useful way of integrating it with politics.

### 3.2.7 Data collection

Three technologies, referred to as the '3S' technologies, which collect and use spatial data, are particularly significant for urban planning; they are geographic information systems (GIS), remote sensing (RS) and global positioning systems (GPS): '3S' technologies (GIS, RS and GPS), which covered the plan structure, socioeconomic indicators and the immense quantity of spatial data are advantageous in urban planning (Zhan *et al.*, 2018). Using geographical data is necessary to create a holistic approach for urban planning. These technologies have been used for over a decade in the field of urban planning. It is now time to direct efforts to ensure sustainable practices and outcomes for cities.

### 3.2.8 Food systems

There are many different names that refer to sustainable cities. For the purpose of this study, the eco-city best describes the connection with all three of the units of observation, namely, food system, climate change and green city. In recent years, the food system had received more attention in research, due to the number of challenges that had arisen in recent years, as was found in the SLR of the previous chapter. Urbanisation, urban sprawl and population growth have required the food system to adapt, because there are now more people who need food and because cities are growing larger. Furthermore, the distance from where the food is grown to where it is delivered and sold in the city centre but not only in the city centre, also in all the other neighbourhoods is increasing. The tools and techniques found seek to implement solutions to reduce the risks of malnourishment and reduce food wastage.

"*Building integrated agriculture (BIA) is the practice of locating high-performance hydroponic greenhouse systems on and in mixed-use buildings to exploit the synergies between the building environment and agriculture-like energy and nutrient flows*" (Specht *et al.*, 2014, p. 35). Increased usage of mixed-use capabilities will become more common in the future, as integrating food systems with the built environment has a plethora of advantages. For example, increasing the amount of greenery in the heart of a city is useful as an adaptive measure to reduce the negative impact of climate change. Another advantage is that it reduces the distance that fresh food must travel into the city for consumption. The positive synergies are plentiful, but the tools and techniques still need to be adjusted to suit context-specific situations in order to become economically feasible.

### 3.2.9 Climate change

The issue of climate change was the most talked about issue among today's sustainability institutions. This study thus seeks to assist in reducing the impact of climate change, starting with how cities contributed to the problem – as well as how they can contribute to the solution.

Climate change is inevitable; there is no denying this. Ice caps are melting, which is both heating up the Earth and drowning it simultaneously. "*Climate planning seeks to combine climate change mitigation and adaptation*" (Wamsler, Brink and Rivera, 2013, p. 78). The biggest contributors to climate changes are from the users of carbon dioxide emissions. This mainly comes from burning fossil fuels in power plants to generate electricity or from fuel consumption by vehicles. Emission processes are highest within cities, where large numbers of people are gathered. The best course of action would be to reduce the carbon footprint of cities by helping them to adapt to climate change and reduce their effect on the environment. Taking responsibility for decreasing fossil fuel usage would be the most effective implementation. Keeping in mind the increasing supply of energy and fuel due to urbanisation, urban sprawl and population growth are making climate change mitigation more difficult.

### 3.2.10 Green city

Integrating the environment into an urban setting is more important now than ever in the urban planning profession. "*Landscape ecology is the study of interactions among landscape elements. Landscape ecology generates an understanding of how spatial pattern affects ecological processes*" (Wikantiyoso and Tutuko, 2013, p. 7). The green city unit of observation included the limited amount of space in cities and implementing environmentally sustainable practices.

### 3.2.11 Resilience

The last paradigm was adaptation planning. The units of observation in this paradigm are resilience, disaster prevention and anti-fragility. This paradigm had the least number of tools and techniques; however, they may be the most important. The previous paradigm had the climate change unit of observation, which will dictate the adaptation planning paradigm for the next decades. The units of observation will need to implement city planning to reduce negative effects that could arise if climate change goes unchecked. This study needs to understand the tools and techniques that contributed to solving the three challenging phenomena identified in the previous chapter: (i) urbanisation, (ii) urban sprawl and (iii) population growth. Within the adaptation planning paradigm, the following examples of tools and techniques explained each unit of observation.

The key aim of resilient methods is not to work against processes. It implies that interactions with communities and eco-systems need to understand and *go with the flow*. "*Communities seemed to give highest importance to so-called green and blue infrastructure, which includes the re-naturalization of ecosystems, and implies working with natural processes instead of against them*" (Wamsler, Brink and Rivera, 2013, p. 76). Natural systems have been around for millions of years and have adapted and evolved. It would be unwise to compete with the natural order of nature or the natural climate. Therefore, designing cities should incorporate natural infrastructure, instead of basic structures that do not resonate with the landscape.

### 3.2.12 Disaster prevention

Within the paradigm of adaptation planning, there is the unit of observation of disaster prevention, which was prevalent in low income areas. "*GIS spatial analysis methods and 3D visualized analysis (LiDAR (Light Detection and Ranging)), can support generation of a rural and urban planning scheme for disaster prevention*" (Zhan *et al.*, 2018, p. 122). The above-mentioned tool and technique requires a large amount of high-quality data to generate useful information that can inform a fool-proof scheme that addresses the risk of disasters. Such disasters can be man-made or natural. Natural disasters are increasing in frequency in both developed and developing countries due to climate change. Therefore, it is important to gather as much data as necessary to reduce economic or even human losses.

### 3.2.13 Anti-fragility

The term anti-fragility is new in the research field of urban planning. "*Antifragilism is not common in the current combination of increasing uncertainties and approach yet. However, unalterable cityscapes mean the risk of a growing number of places being under threat is rising. Therefore, it was necessary to acknowledge the potential upcoming of a new wave in sustainable urbanism and start research and practical applications in design projects*" (Roggema, 2016, p. 7). This study did not specifically search for this type of technique. However, there is a possibility that urban planning can implement anti-fragility to reinforce the resilience of the urban system and its ability to improve, even after undesirable influences. The units of observation will be discussed and assessed in Section 3.7.

## 3.3 Paradigms

Step 2 of the categorisation method is identifying the paradigms. The Cambridge Dictionary defines 'paradigm' as: "*a model of something, or a very clear and typical example of something.*" Therefore, for the purposes of the study, the tools and techniques used by sustainable urban planners were grouped into five paradigms: (i) sustainable urban planning, (ii) sustainable development, (iii) smart city, (iv) green city and (v) adaptation planning. These paradigms are derived from the units of observations, discussed in Section 3.2.

### 3.3.1 Sustainable urban planning

The sustainable urban planning paradigm was the central focus of this study, and it is the paradigm that is associated with the tools and techniques. There was bias associated with this paradigm because it contained all the search terms allocated to the Boolean search string from the SLR. However, this was not a determining factor for assessment. The units of observations associated with it were urban form and planning. These two were very important to designing and managing a city. They form the structure of a city. Regarding the sustainability aspect, urban planning needs to ensure that all elements are addressed evenly: environmental, social, economic and governance. 'Evenly' is the important part of that statement. In other words, it is not enough to approach an urban planning task by fulfilling economic goals only. The theme of this study is to identify the implementable solutions that can satisfy the future generations' needs – environmentally, socially and economically. Within the sustainable urban planning paradigm, the following examples of tools and techniques explained each unit of observation.

Sustainable urban planning involves many disciplines, including architecture, engineering, transportation, technology, economic development, accounting and finance, and government. This kind of planning also provides advanced and applied methods to influence land use and the natural resources positively.

An example of the tools and techniques that would fit this paradigm is "*the smart-compact-green city framework. which can be considered an indicator-based target system, which approaches: 1) smart compact cities considering the need to limit urban sprawl through smart growth, and 2) smart green cities reflecting the preservation and (re-development of urban green infrastructure)"* (Artmann *et al.*, 2019, p. 11). This paradigm combines all the best practices from the urban planner's arsenal, which try to deal with the challenges described in the previous chapter: (i) urbanisation, (ii) urban sprawl and (iii) population growth.

### 3.3.2 Sustainable development

According to the 1987 United Nations report, sustainable development is "*the development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". This definition was the cornerstone of this study. An example of a tool that fits the sustainable development paradigm was the "*New Urban Agenda, which aims to harness the potential of cities and human settlements to help eradicate poverty in all its forms and dimensions, reduce inequalities, [and] promote inclusive growth. Hence it provides a new global framework to develop sustainable cities*" (Roggema, 2016, p. 2). This paradigm is similar to sustainable urban planning. Sustainable development represents all aspects of sustainability in developmental situations, comprising social, economic and environmental aspects of development. Furthermore, sustainable development was not restricted to the confines of cities, but also included the connection between urban and rural areas, such as water management, which was discussed in Section 3.2.4.

### 3.3.3 Smart city

A Smart City, according to the Stellenbosch Smart Mobility Lab (SSML), uses data, information technology and communications to optimise infrastructure usage and improve service efficiency in a city's energy grid, communications, infrastructure management, water provision and transportation system. "*Smart cities can be referred to as a smart economy (e.g., communication and information technologies), smart people (e.g., human capital), or smart governance (e.g., e-governance or e-democracy)*" (Artmann *et al.*, 2019, p. 11). This is positively associated with sustainability, because it takes into account economics, social aspects and governance. Smart cities also incorporate the IoT and big data.

### 3.3.4 Eco-city

An eco-city is a human settlement modelled on the self-sustaining resilient structure and function of natural ecosystems. A technique that is used within this paradigm is known as an "*Eco-Town is where most of its activities depended on green technologies that were based on several concepts, including the 3R (Reduce, Reuse and Recycling) concepts as well as building an economy based on the life-cycle approach*" (Laffta and Al-Rawi, 2018, p. 4). Several green technologies must be incorporated to develop an eco-city. An important note is the reference to building an economy. Many critics do not envision that eco-cities can have an economic payback. There is certainly a green economy that is centred around the green technologies that can develop a viable economic structure. It is up to researchers to get their hands dirty and reveal the opportunities of solutions that reside in the concept of the eco-city.

### 3.3.5 Adaptation planning

An example of adaptation planning is ensuring that cities create flexible governmental planning procedures and thus become more resilient in the face of disasters (Wendt, 2015). This is related to units of observations, such as climate change, resilience and anti-fragility, which were discussed in Section 3.2.

Adaptation planning is future orientated. "*A prediction map shows the probability of occurrence of geological hazards*" (Zhan *et al.*, 2018, p. 112). The prediction map tool the probabilities and risks associated with planning in response to natural disasters. Adaptation planning requires urban planners to have access to large amounts of data in order to make informed decisions. Developing countries are extremely vulnerable to natural disasters. This can be a contributing factor to poverty and to their current status of 'developing country'. Developing countries in areas of the world that are especially susceptible to climatic disruptions are always held back with regard to economic growth, because they must continually rebuild after natural disasters, which uses up resources that could otherwise be used for economic growth. For these countries to compete with first world countries, they need to implement resilient and adaptive measures and practices to reduce or avoid the calamities that continually set back their progress.

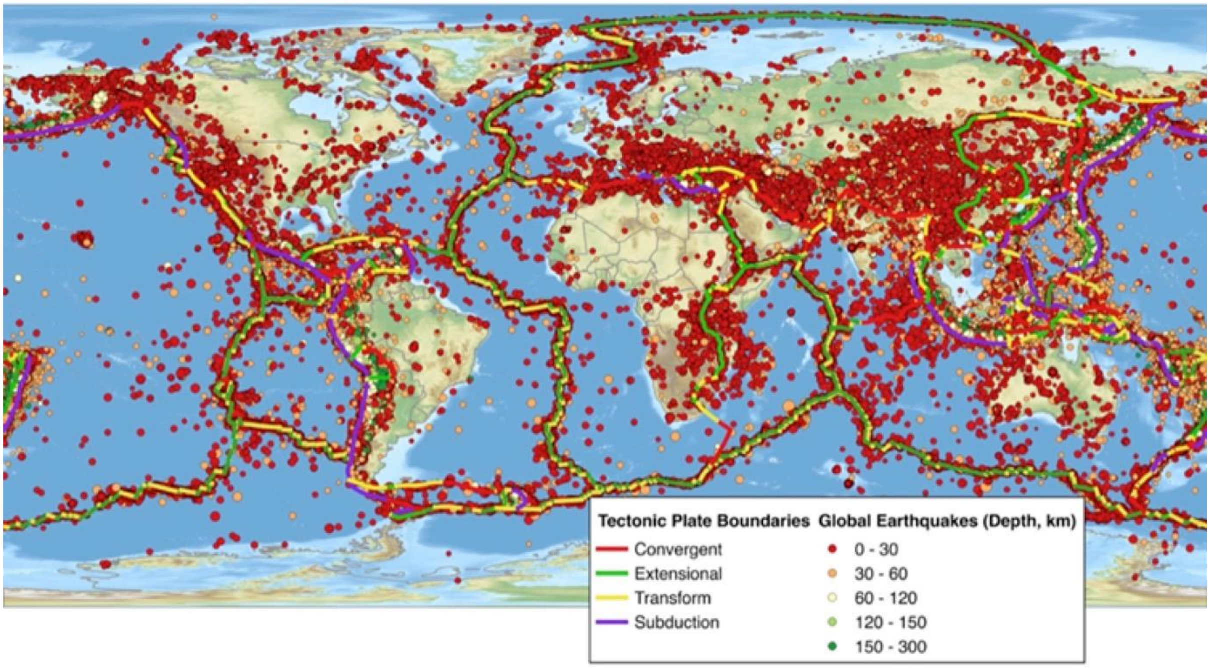



*Figure 3.3: The global distribution of earthquakes in the period from 1900 to 2014, and global plate boundaries. Source: (UNISDR, 2017)*

Figure 3.3 illustrates the tectonic plate boundaries, and which countries would be affected by movements along these boundaries. There is a plate boundary on the East African Rift Valley, where the shallow crust is extending, causing mild to intensive seismic activity (UNISDR, 2017). East Africa contains many low-income developing countries with large urban centres, which are at risk of possible earthquakes. Another notable high-risk area is the convergent plate boundary in the area of Pakistan, India, Nepal and China that is producing continental collisions, resulting in tectonic compression (UNISDR, 2017). These countries are fully aware of the risks of earthquakes, but they pose a particularly large threat due to the large populations that live in both urban and rural areas of these countries, and this threat is thus bigger than that faced by developed countries. For example, there is an active tectonic plate boundary along the west coast of the USA; the difference is that the USA is a developed country with the means, and the plans in place, to resist or adapt to the disturbance much more quickly than their underprivileged counterparts in the developing world. This underscores the importance of resistive measures for developing countries to defend themselves against natural disasters.

Gradual changes in precipitation patterns result in either floods or droughts. "Developing countries are vulnerable to extreme weather events in a present day climatic variability and this causes substantial economic damages" (Mirza, 2003). Moreover, the increased variability of extreme weather conditions related to changes in surface temperature also affects mainly arid, coastal, water limited or flood prone areas (Mirza, 2003).

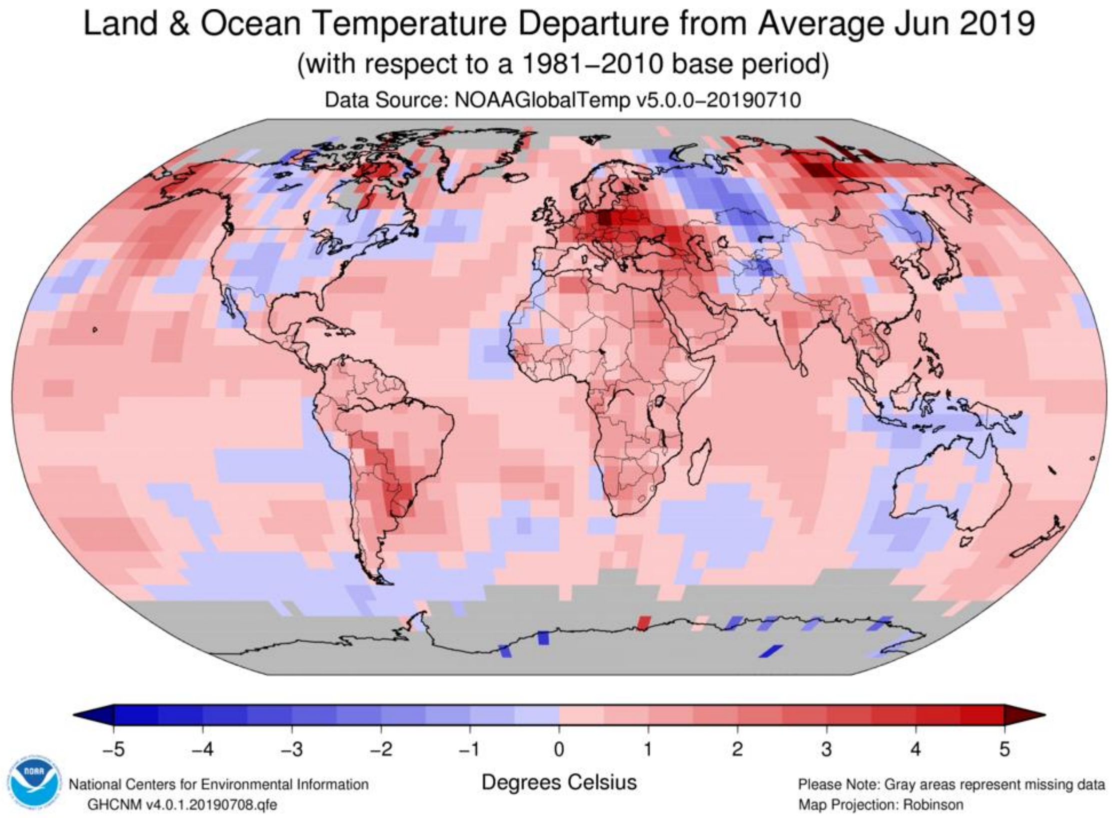



*Figure 3.4: June 2019 blended land and sea surface temperature anomalies in degrees Celsius. Source: (NOAA, 2019)*

Figure 3.4 illustrates the changes in mean temperature over the last 38 years (NOAA, 2019), showing two extreme events occurring in North America and Europe. North America is facing a reduction in the average surface temperature by almost 2 degrees Celsius, whereas Europe is affected by a 4-5 degree Celsius increase. However, the mean surface temperature in developing countries in Africa and South America will increase by 2-3 degrees Celsius. The variabilities of climatic conditions will cause significant disruptions in economic and social situations, natural resources and adaptive capacity (Mirza, 2003), which adds to the importance for developing countries to install adaptive measures to combat climate change now, before the cost of conservation becomes prohibitive.

## 3.4 Units of analysis

Step 3 of the categorisation method is identifying the units of analysis. Units of analysis is defined as "*the phenomena under study may be sorted or arranged for purposes of systematic analysis, and relates to the question whether to focus upon the parts or upon the whole*" (Nuri Yurdusev, 1993, p. 77). As stated previously, in this study, the unit of analysis refers to the location or setting in which users are looking to initiate or implement their sustainable urban plan. This study was associated with a developing country context. Therefore, it is important to identify the different areas of analysis that occurred. On the basis of physical and infrastructural characteristics, the settlement categorisation can vary between formal and informal, and urban and rural (Smit *et al.*, 2017). Table 3.1 shows the categorisation of this unit of analysis.

*Table 3.1: Units of analysis categorisation. Source: (Niva, Taka and Varis, 2019)*

| | **Formal** | **Informal** |
|---|---|---|
| **Urban** | Urban/formal | Urban/informal |
| **Rural** | Rural/formal | Rural/informal |

Examples of each include:

i. Urban/Formal: Built up city environment. High concentration of planned infrastructure;
ii. Urban/Informal: Informal settlement in the centre of town;
iii. Rural/Formal: Suburban area. Neighbourhoods situated approximately 20 km away from city centre; and
iv. Rural/Informal: Outside the border of city limits where there is no planned infrastructure. Agricultural area on the outskirts of city.

## 3.5 Qualitative versus quantitative methods

Step 4 of the categorisation method is identifying the qualitative versus quantitative methods. For the content analysis, different groups needed to be formed to define the inputs necessary for the MCDA. One of the groups involves asking if the tools or techniques featured a qualitative or quantitative study. This refers to the type of content that was available or used for compiling the tool or technique. Quantitative data is information that is measured, understood, and written by using numbers, whereas qualitative data are more wide-ranging: "*The researcher has several methods for collecting empirical materials, ranging from the interview to direct observation, to the analysis of artefacts, documents, and cultural records, to the use of visual materials or personal experience*" (Denzin and Lincoln, 1995, p. 349).

## 3.6 Type of approach

Step 5 of the categorisation method is identifying which spectrum – or type of approach – they resided in. Figure 3.5 shows the four quadrants that the tools and techniques were placed in to further assess their differences.

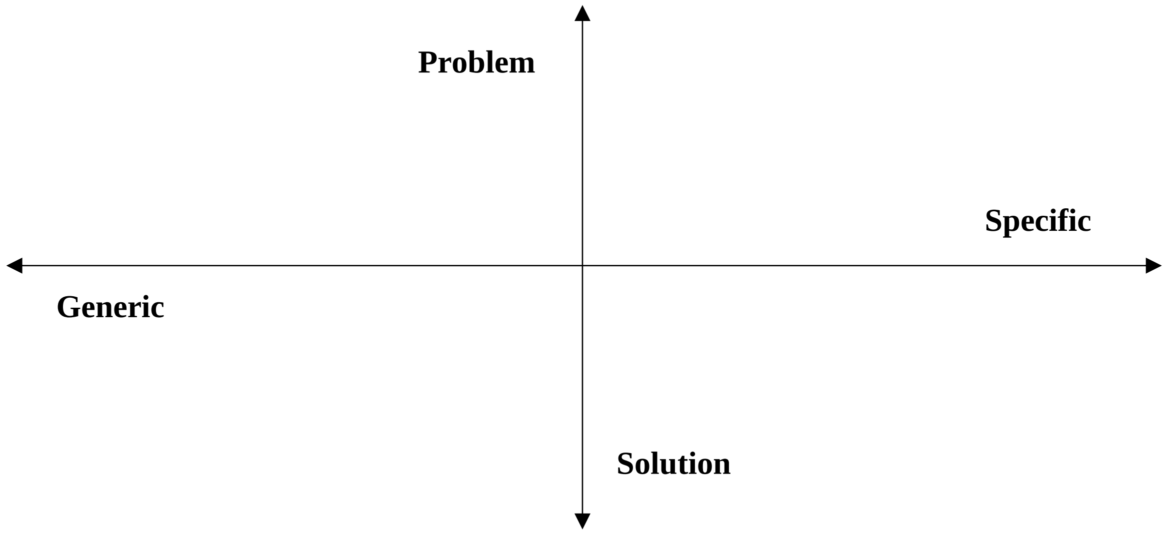



*Figure 3.5: Type of approach quadrants*

If the approach was located within the ‘Problem’ half, it meant that the approach dealt with the problem side, whether this related to data collection or the beginning of the process before the analysis began. The ‘Solution’ half included the approaches that dealt with the implementation. The ‘Generic’ vs ‘Specific’ halves, in relation to sustainable urban planning, meant that, if a tool and technique was a ‘Generic’ approach, it was used in a range of other scenarios not connected with sustainable urban planning, whereas if it was a ‘Specific’ approach, it was used only in the context of sustainable urban planning. The following four subsections explain each of these quadrants illustrated in Figure 3.5.

### 3.6.1 Problem-Generic quadrant

The tools and techniques associated with this approach addressed a problem that was not directly connected to sustainable urban planning. A tool or technique that represented this quadrant would be photovoice or participatory photography (Masterson, Mahajan and Tengö, 2018). These techniques were very similar and began with identifying the problem associated with the urban planning project, and taking photos of people in rural settings going about their normal lives. Then, the photographer conducted an interview with the participants regarding the photos. The difference between the photovoice and ordinary interviews were the visual stimulus that is conveyed alongside the words to describe the picture. The problem-generic tools and techniques began the identification process. Next, they require analysis of the information before any judgements or intervention can be processed. This is the defining element that tools and techniques required for the MCDA conducted in Chapter 4.

### 3.6.2 Problem-Specific quadrant

Tools and techniques in this quadrant were associated with problems that had a direct connection with sustainable urban planning. Problem-specific tools and techniques are like problem-generic approaches. The main difference is that these tools and techniques still only identified the problem and generated data. The differences and similarities between the approaches throughout the process can be shown in Figure 3.6.

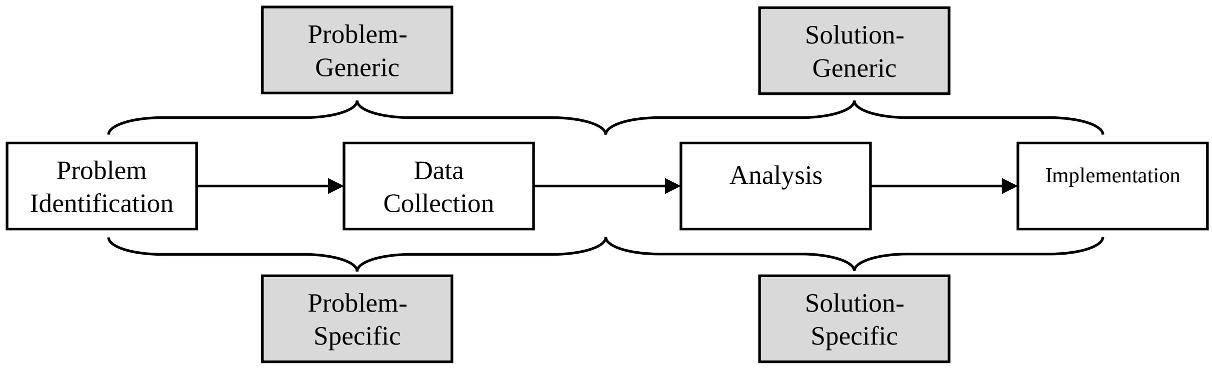



*Figure 3.6: Differences between the types of approaches*

In Figure 3.6 the different approaches were represented throughout a general problem-solving process, which proceeded from problem identification to data collection to analysis to implementation. As the represented in the diagram, the problem-generic and problem-specific tools and techniques were found within the problem identification and data collection stages. The following two stages (analysis and implementation) fall within the solution-generic and solution-specific range.

### 3.6.3 Solution-Generic quadrant

This type of approach included tools or techniques that were not specifically aligned with sustainable urban planning topics. An example of a solution-generic tool would be the enhanced Drivers-Pressures-States-Impacts-Responses framework (eDPSIR) (Ding *et al.*, 2015). Most frameworks were found in the solution half of Figure 3.5. Because frameworks required data for a specific problem, after inputting data, the framework conducted analysis, and implemented and deduced a solution based on information that had been given. An important difference between generic and specific tools and techniques was the element of sustainable urban planning upon which they are based.

### 3.6.4 Solution-Specific quadrant

Tools and techniques that were relevant to implementing sustainable urban planning practices and results were placed into this quadrant. The tools and techniques in this quadrant will be further elaborated on in Sections 3.8 and 3.9 by discussing the requirements and offerings of the solution-specific tools.

## 3.7 Assessment of the tools and techniques landscape

The five categories (units of observation, paradigms, unit of analysis, qualitative vs quantitative, and type of approach) have been defined and the reasons for their choice have been presented in the preceding sections (Sections 3.2 to 3.6). The next step is to continue with the content analysis. Having gathered all the qualitative information regarding the tools and techniques found in the SLR, the next step is to quantify the data. In this section, therefore, the tools and techniques landscape will be assessed according to the five categories.

### 3.7.1 Assessing the units of observation

Figure 3.7 shows 236 tools and techniques that were divided into the 13 different units of observation. As mentioned previously, urban form and planning were placed into the sustainable urban planning paradigm. It can be seen that this covered 124 tools and techniques within the literature study, thus accounting for more than 50 percent of the total number of tools and techniques. However, there were biases involved with this interpretation, as those were identified as the search terms within the Boolean search criteria. The next five notable units of observation had more than 10 tools and techniques each: water management, ICT, data collection, food systems and disaster prevention with 16, 18, 13, 19 and 12 respectively. It must be noted that the number of tools and techniques within each unit of observation did not correlate to their importance. Instead, it merely reveals what the sustainable urban planning researchers had deemed important to develop or use over the last seven years. These five notable units of observation exposed the important tools and techniques that needed to be developed or used more often within sustainable urban planning. Water management, ICT, data collection, food systems and disaster prevention share certain similarities; acommon theme was to incorporate new technological inovation to manage important human needs, namely: the right to clean water, the right to nutritional and healthy foods, and the right to security in the face of natural or man-made disasters.

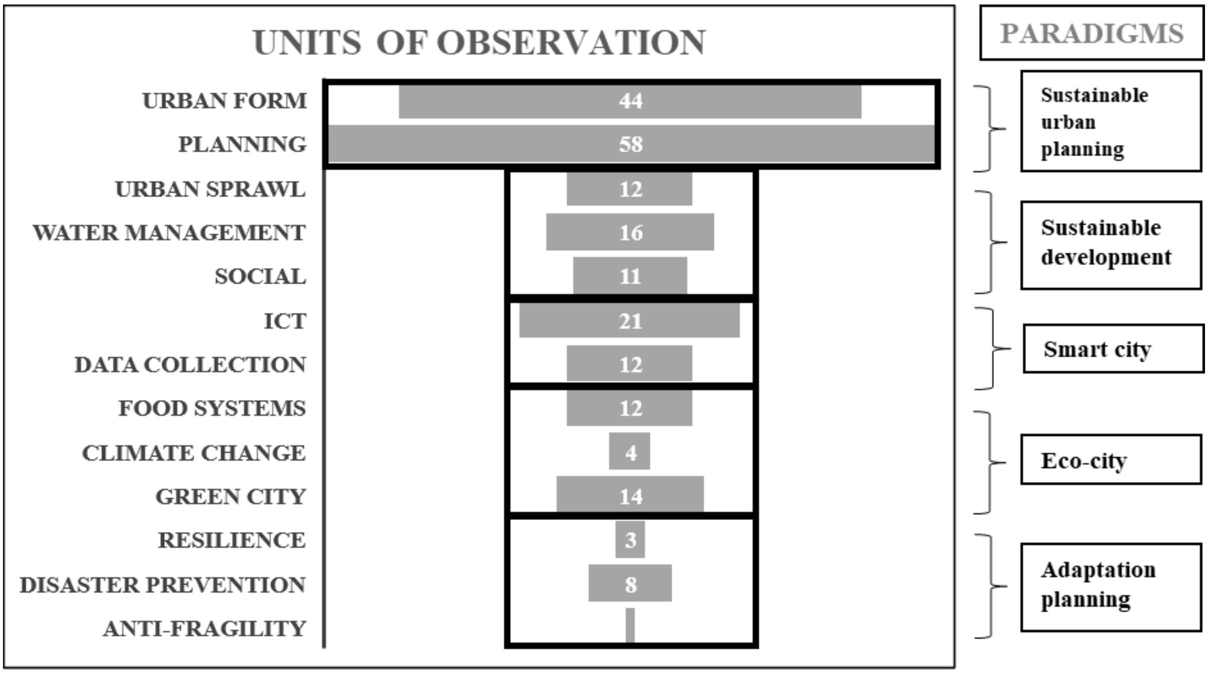



*Figure 3.7: Units of observation*

The takeaway from this assessment should highlight the connection that urban planners have to the right of human beings' access to resources. It furthermore emphasises that urban planners in developing countries are resopnsible for ensuring that the needs of their cities' inhabitants are met. This message should be understood by the governing bodies and large corporations who make the major decisions with a lack of regard for the important role of an urban planner. Section 3.2 showed how the units of observations were chosen and grouped together into similar categories, by developing the overarching paradigms that the units of observations fall under. The link between the units of observation and the paradigms is an important input for the research product. In order to input parameters into the research product, the user must first select the relevant paradigm, followed by the unit of observation that closest relates to their query. The design of the research product can be found in Chapter 6. Sections 3.3.1 to 3.3.5 discussed the similarities of the units of observations that are grouped in each paradigm.

### 3.7.2 Assessing the paradigms

Figure 3.8 shows the number of tools and techniques that were found in each of the paradigms. Note that the sustainable urban planning paradigm contains most of the tools and techniques. This is due to the bias factor stemming from the search criteria in the SLR.

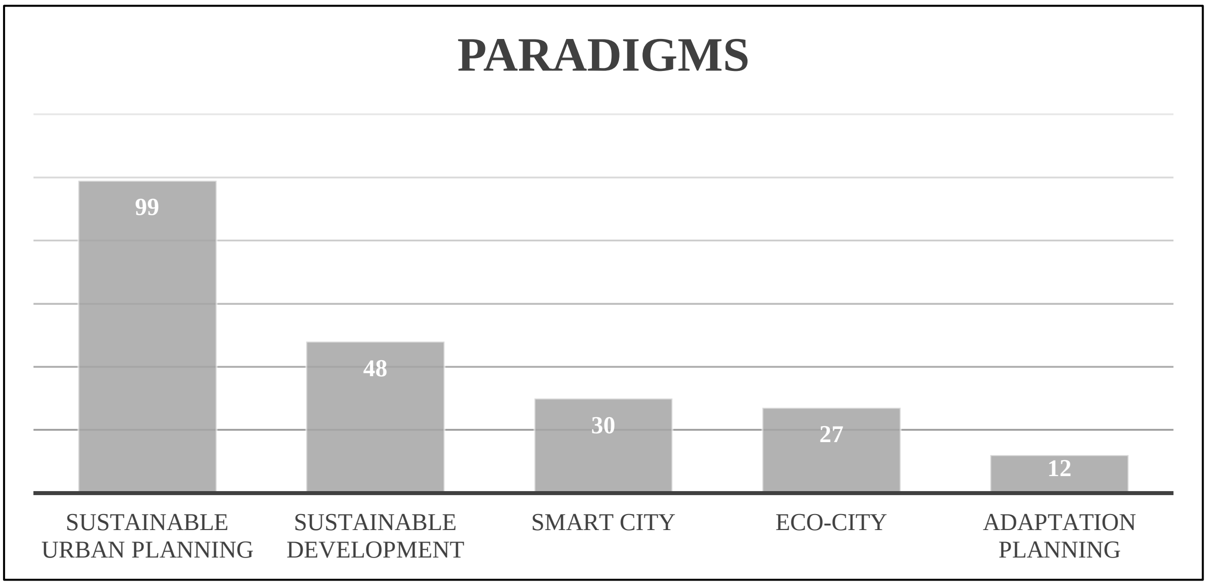



*Figure 3.8: Cumulative paradigms*

### 3.7.3 Assessing the units of analysis

As mentioned before, the unit of analysis in the context of urban planning defines the setting or location within which the tool or technique functions. Section 6.4.1.1 elaborates on how the input will contribute toward finding a strategy to support the user's decision for sustainable projects in urban planning within developing countries.

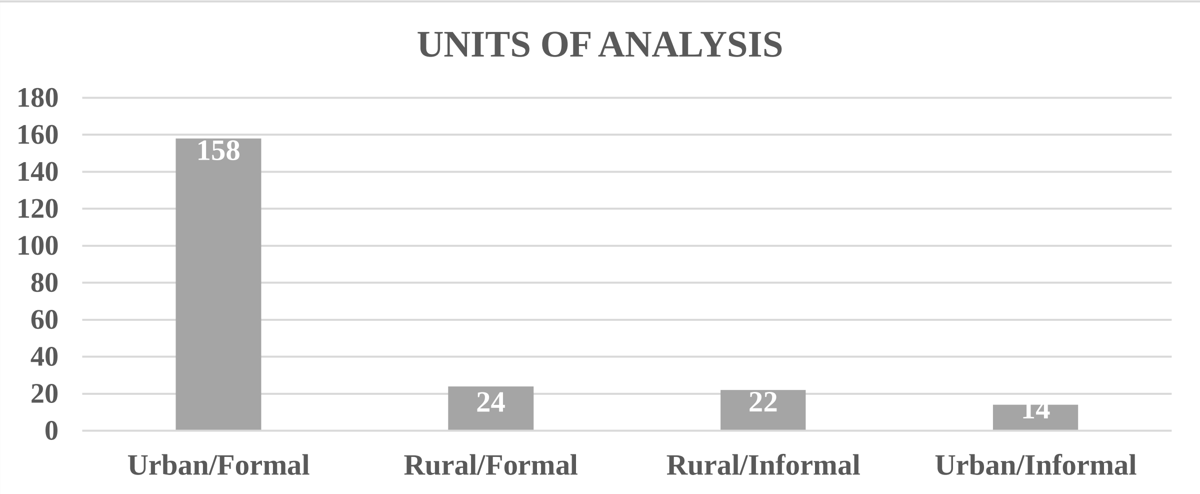



*Figure 3.9: Cumulative units of analysis*

Figure 3.9 shows the number of tools and techniques found within each set of the unit of analysis as set out in Table 3.1, with regard to urban/rural and formal/informal. Urban/formal was the clear preferred setting for analysis. This was attributed to the search criteria from the SLR, which focused on the development of cities. The unit of analysis category will be one of the inputs that the user needs to choose when operating the research product that will be produced from this study.

### 3.7.4 Assessing the qualitative versus quantitative methods

Figure 3.10 is a pie chart that depicts how many qualitative versus quantitative methods were identified. Figure 3.10 shows that most research in the last seven years in the field of sustainable urban planning used tools and techniques of a qualitative nature. This meant that in developing countries research was conducted practically. In contrast, implementing tools and techniques that generate quantitative data or results were more difficult to achieve. There was thus a gap for further research to identify quantitative studies within developing countries in the field of sustainable urban planning. In the case of the research product of this thesis, the question of which type of data is available will filter the end decision toward a qualitative or a quantitative tool or technique. This will be elaborated on further in the requirements specification and the functional analysis in Section 5.1 and Section 6.4 respectfully. The challenge arises when trying to find a tool or technique for developing countries that is quantitative in nature.

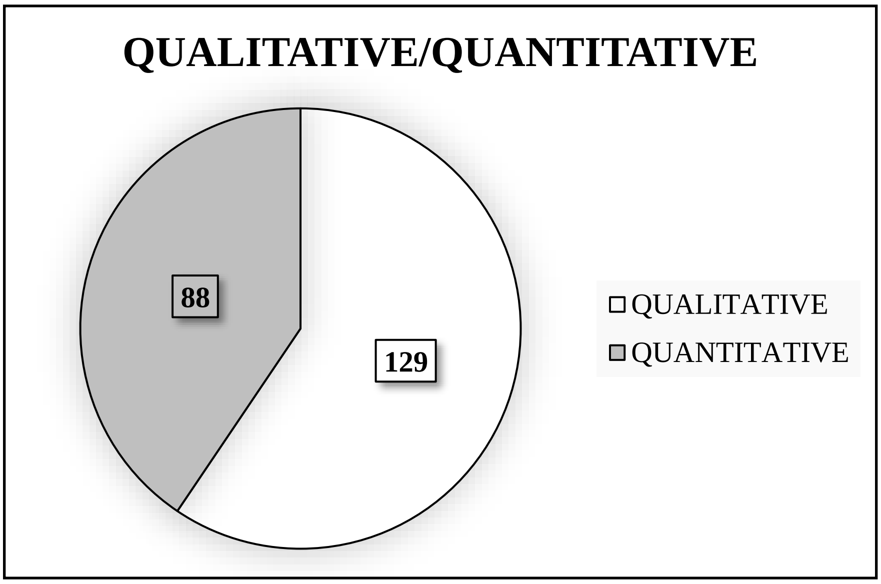



*Figure 3.10: Pie chart of qualitative and quantitative tools and techniques*

### 3.7.5 Assessing the solution-specific approach

These tools and techniques need to connect with the three challenges mentioned in the previous chapter (urbanisation, urban sprawl and population growth). To link these challenges, the type of approach also needed to be aligned with a solution-specific type. Therefore, the outcome was a sustainable urban planning solution centred toward implementation.

*Table 3.2: Solution-specific tools and techniques*

| Approach | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative |
|---|---|---|---|---|
| Smart Sustainable City (SSC) | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Successful Neighbourhood Model (SNM) | Sustainable development | Rural/Formal | Sprawl | Quantitative |
| Smart growth | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Systemic conceptual framework for compact and green cities | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Smart-compact-green city framework | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| GIS analysis | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Landscape design | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Land-use regulation | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Sustainable water management | Sustainable development | Urban/Formal | Water management | Quantitative |
| Sustainable and green infrastructure | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Green Road Concept | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Eco-Town | Eco-City | Urban/Formal | Green City | Qualitative |
| Smart development | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Retrofitting | Sustainable urban planning | Urban/Formal | Urban form | Quantitative |
| SOLWEIG | Eco-City | Urban/Formal | Climate change | Quantitative |
| PALM | Sustainable urban planning | Urban/Formal | Urban form | Quantitative |
| ESTIDAMA | Sustainable urban planning | Rural/Formal | Planning | Qualitative |
| Conceptual Design Matrix for Sustainable Urban Form | Sustainable urban planning | Rural/Formal | Urban form | Qualitative |
| Neotraditional Development and Urban Containment | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Floor area ratios (FAR) | Sustainable urban planning | Rural/Formal | Urban form | Qualitative |
| Energy landscapes | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Sustainable urbanism | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Anti-fragility | Adaption planning | Urban/Formal | Anti-fragility | Qualitative |
| New Urban Agenda | Sustainable development | Urban/Formal | Social | Qualitative |
| Green urbanism | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Compact city | Sustainable urban planning | Urban/Formal | Urban Form | Quantitative |
| Sustainable urbanization framework | Sustainable urban planning | Urban/Formal | Planning | Quantitative |
| Trinity of cities sustainability | Sustainable urban planning | Urban/Formal | Planning | Quantitative |
| Compact coefficient of urban area (CCUA) | Sustainable urban planning | Urban/Formal | Urban form | Quantitative |
| Green belt | Sustainable development | Rural/Formal | Sprawl | Qualitative |
| Polycentric networks | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Urban agriculture | Eco-City | Urban/Formal | Food system | Qualitative |
| Green urban architecture | Eco-City | Urban/Formal | Food system | Qualitative |
| ZFarming | Eco-City | Urban/Formal | Food system | Qualitative |
| Edible city | Eco-City | Urban/Formal | Food system | Qualitative |
| Brownfield development | Eco-City | Urban/Formal | Food system | Qualitative |
| Vertical farming | Eco-City | Urban/Formal | Food system | Qualitative |
| Building integrated agriculture (BIA) | Eco-City | Urban/Formal | Food system | Qualitative |
| Eco-effective architecture | Eco-City | Urban/Formal | Food system | Qualitative |
| Green Revolution | Eco-City | Rural/Informal | Food System | Qualitative |
| Blue Revolution | Sustainable development | Rural/Informal | Water management | Qualitative |
| Water policy | Sustainable development | Rural/Informal | Water management | Qualitative |
| SWAGMAN | Eco-City | Rural/Informal | Food System | Qualitative |
| New urbanism | Sustainable urban planning | Rural/Formal | Planning | Qualitative |
| Smart Growth Network (SGN) | Sustainable urban planning | Rural/Formal | Planning | Qualitative |
| Leadership in Energy and Environmental Design (LEED) | Sustainable urban planning | Rural/Formal | Planning | Qualitative |
| Water-sensitive urban design (WSUD) | Sustainable urban planning | Rural/Formal | Urban form | Qualitative |
| Corridor development | Sustainable urban planning | Urban/Formal | Urban form | Qualitative |
| Non-transport policies | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Transit-oriented development | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Planning for less travel | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Mixed-use strategy | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Adaption planning | Adaption planning | Urban/Formal | Disaster prevention | Qualitative |
| City-disasters nexus | Adaption planning | Urban/Formal | Disaster prevention | Qualitative |
| Disaster resilient city | Adaption planning | Urban/Formal | Disaster prevention | Qualitative |
| Climate planning | Adaption planning | Urban/Formal | Disaster prevention | Qualitative |
| The Green New Deal | Eco-City | Urban/Formal | Food system | Qualitative |
| Eco Cities | Eco-City | Urban/Formal | Food system | Qualitative |
| Green-capitalism | Eco-City | Urban/Formal | Food system | Qualitative |
| Township and Village Enterprises (TVEs) | Eco-City | Urban/Formal | Food system | Qualitative |
| Green economic investment | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Bus rapid transit (BRT) | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Local Governments for Sustainability's (ICLEI's) | Sustainable urban planning | Urban/Formal | Planning | Qualitative |
| Peri-urban agriculture (UPA) | Sustainable urban planning | Urban/Formal | Food system | Qualitative |
| Green city design | Eco-City | Urban/Formal | Green city | Qualitative |
| Urban green space | Eco-City | Urban/Formal | Green city | Qualitative |
| Landscape ecology | Eco-City | Urban/Formal | Green city | Qualitative |
| 3Rs (Reducing, Reusing, and Recycling) | Eco-City | Urban/Formal | Green City | Qualitative |
| Roof gardening | Eco-City | Urban/Formal | Green City | Qualitative |
| Concentric circles | Sustainable urban planning | Urban/Formal | Urban form | Quantitative |

The 70 tools and techniques found in Table 3.2 are identified as the methods that will have the greatest effect on urban planning projects with regard to ensuring sustainable outcomes. Before connecting the tools and techniques to the challenges, it is helpful to summarise the units of observations relating to the appropriate type of approach. Regarding sustainable urban planning, the type of approach that will be further assessed falls within the "solution-specific" quadrant. Tools and techniques within this quadrant refer to those that were centred around analysis and implementing sustainable solutions to urban planning challenges. Grouping these tools and techniques will thus be the first step to connecting the challenges; thereafter, the solution-specific approaches will be identified and what they offer once they have been applied.

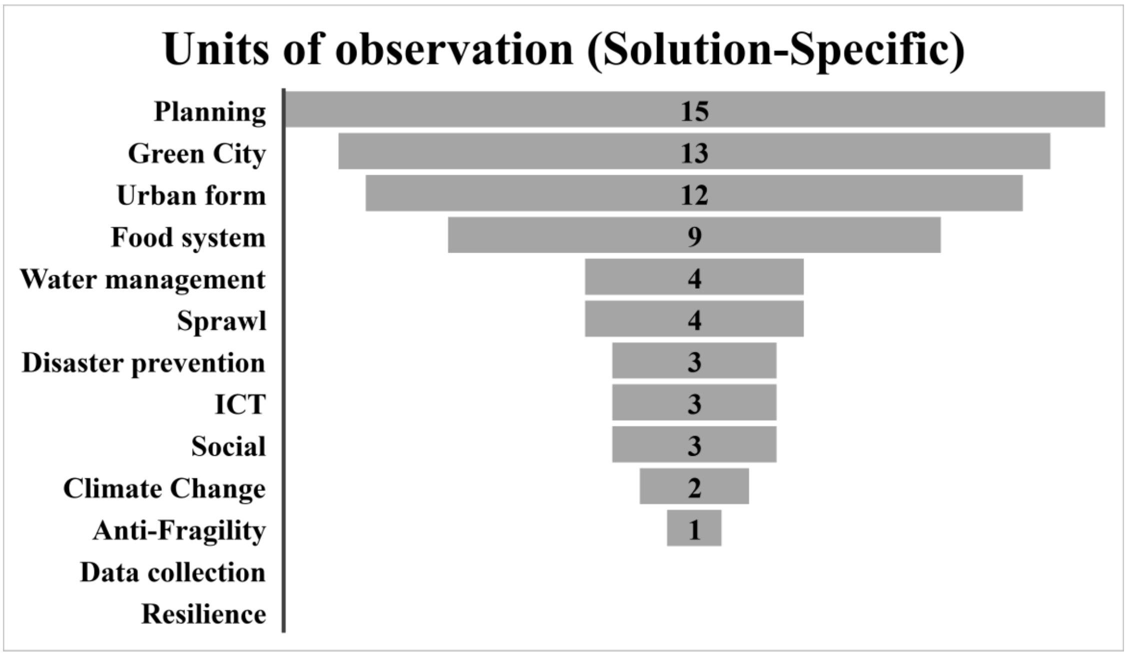



*Figure 3.11: Cumulative unit of observation (solution-specific)*

Figure 3.11 shows the difference in the number of tools and techniques that were aligned with the units of observations mentioned in the first units of observation graph (Figure 3.7). The graph revealed that in the solution-specific domain there were no longer any ICT, data collection and resilience units of observation. This showed that, in the context of developing countries, there was no notable mention of research in the last seven years that had produced or used tools and techniques in the sustainable urban planning domain that centred on implementing a solution. Moreover, it revealed a disparity between ICT and data collection that was very prevalent in Figure 3.11; now these were underrepresented. This could be due to the lack of data or the lack of expertise within developing countries, which could have led to the poor implementation of these tools and techniques. Conversely, these units of observation were not aligned with the specific context of sustainable urban planning. Regarding resilience, this is a very new field of research, especially in the area of sustainable urban planning. The literature suggests that there is a place for resilience and adaptation planning to tackle climate change issues that affect cities today. However, this assessment shows that there have not been any tools and techniques used or developed to ensure the implementation of resilient practices in the context of developing countries.

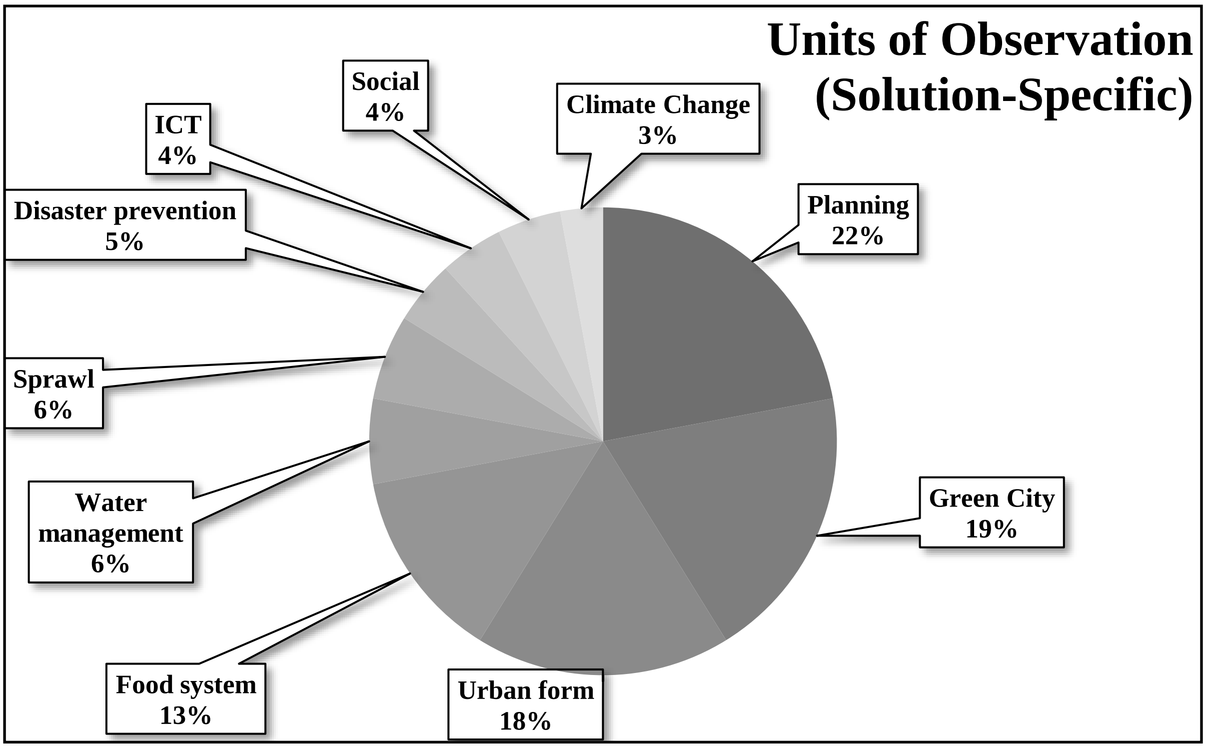



*Figure 3.12: Limited pie chart of solution-specific units of observation*

Now, as shown in Figure 3.12, the main units of observation with the solution-specific domain were: (i) urban form, (ii) planning, (iii) food systems, (iv) green city, (v) disaster prevention, (vi) water management, (vii) urban sprawl, (viii) social impacts, (ix) anti-fragility and (x) climate change, with the number of tools and techniques associated 23, 20, 16, 6, 6, 4, 2, 1, 1 and 1 respectively.

Figure 3.12 thus shows that most of the tools and techniques mentioned in research relating to sustainable urban planning were concerned with urban form, planning, food systems, green city and disaster prevention. The dominant paradigms of this study were sustainable urban planning and the eco-city. However, to reduce bias toward the search criteria, the eco-city paradigm was found to be the subject of interest for most researchers over the last seven years associated with developing countries. They could be centred around developing urban areas with natural areas, while incorporating an agenda to ensure food security for increasing populations in large developing cities. Including nature and food security into a city also has many benefits for sustainability, which would satisfy environmental and social aspects. However, the reason why this is not easy is that businesses have a difficult time understanding the economic possibilities of these approaches. The general business model will thus need to change, but it is very challenging for businesses to be competitive in a developing country context. Consequently, businesses who incorporate environmental and social aspects and sustainability principles are generally less competitive. To change the system, it is vital for good cooperation between industry and research to bridge the gap between sustainable practices an everyday situation. Figure 3.13 is a pie chart comparing the two different methods used in relation to the solution-specific approaches. Of the 70 tools and techniques, 59 were found to be qualitative in nature. Comparing this result to the initial assessment in Figure 3.10 shows that a majority of researchers are using or developing tools and techniques that are theoretical in nature. However, there was an assumption that this was due to the lack of data in developing countries.

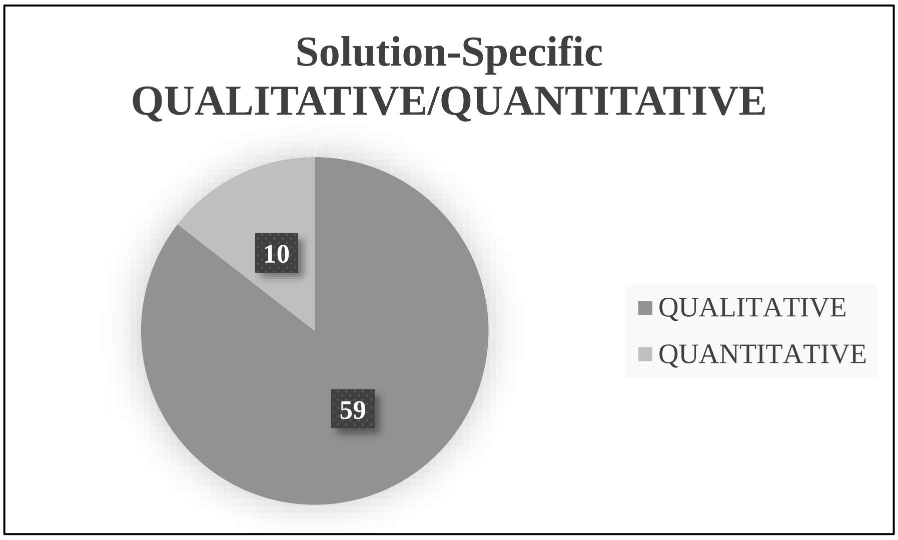



*Figure 3.13: Solution-specific qualitative versus quantitative methods*

This assumption still holds true because, in the solution-specific quadrant, there are no tools and techniques relating to ICT or data collection units of observation types. This sheds some light on the importance of institution and corporations in developing countries and the fact that they need to begin gathering data. This sort of investment is paramount to begin sustainable practices in these underprivileged nations.

There is also clearly a gap in research when developing tools and techniques that ensure the implementation of solutions regarding sustainable urban planning in developing countries, because only 70 out of 236 tools and techniques discussed in relevant research papers were aligned with solution-specific approaches. Figure 3.14 shows the units of observations, with the 11 tools and techniques that were aligned with the quantitative method.

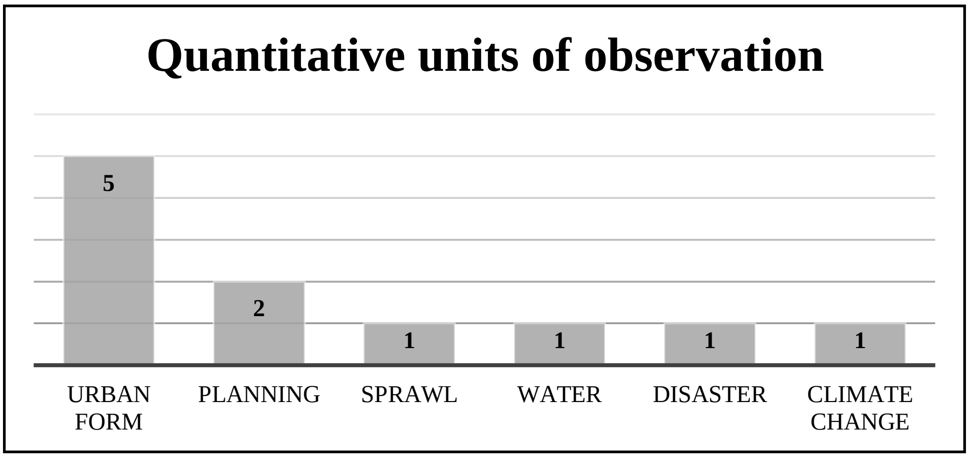



*Figure 3.14: Quantitative units of observation*

Figure 3.14 shows that most of the quantitative methods arose from the urban form unit of observation. Furthermore, the only climate change associated solution-specific tool and technique was looked at in a quantitative study. This information is useful for further analysis regarding the connection between the challenges and the tools and techniques. The five tools and techniques found in the urban form unit of observation were: (i) retrofitting using modern technological solutions, (ii) the Parallelized Large-eddy Simulation Model (PALM), (iii) compact city, (iv) compact coefficient of urban area (CCUA) and (v) concentric circles. These tools and techniques are not new and innovative, but have been used for several years in developed countries. They are only now being addressed in the developing country context. However, these tools and techniques may not work in developing countries, which proves the importance of considering the context when applying sustainability.

## 3.8 Solution-specific tools and techniques requirement

This section is very important for connecting the tools and techniques to the challenges identified in Chapter 1. The investigation begins by considering the five paradigms (sustainable urban planning, sustainable development, smart city, eco-city and adaptation planning). Most of the tools and techniques within the solution-specific domain are associated with sustainable urban planning, due to a bias in the search criteria from the SLR. Moreover, many of the units of observation come from urban form, planning and food system, as can be seen in Figure 3.11 and Figure 3.12. This quick assessment summarises the aggregate tools or techniques for requirements that would be found within these paradigms and units of observations.

### 3.8.1 Solution-specific analysis

In Section 3.6, where the four types of approaches were highlighted, each approach was explained and differentiated from one another. Shedding light on the requirements will facilitate implementation of the tools and techniques. The main difference between solution-specific approaches and other approaches is illustrated in Figure 3.6, where this approach encompasses the analysis and implementation stages of the problem-solving process. Therefore, these stages will identify what the solution-specific tools and techniques require.

Analysis needs the first two stages, which were problem identification and data collection. These two stages needed to be completed before analysis can take place. The more thorough the first two stages are, the greater the quality of the analysis. Solution-specific tools and techniques will thus require enough data to enable the analysis to make a verdict before the next stage of implementation.

### 3.8.2 Solution-specific implementation

The final stage of the problem-solving process is implementation, which requires all three of the previous stages to have been completed properly. An in-depth analysis moreover reveals important steppingstones that would allow for and ensure successful implementation. In conclusion, solution-specific tools and techniques require an abundance of data regarding the specific problem at hand, which must be followed by a detailed analysis that facilitates the final stage, namely, implementation.

## 3.9 Solution-specific tools and techniques

Solution-specific tools and techniques are found within the last two stages, analysis and implementation. It is important to note that these types of approach will still need the first two stages to have been completed properly.

Each tool and technique will offer something different. The solution-specific tools and techniques should aim to solve the challenges related to sustainable urban planning, such as urbanisation, urban sprawl and population growth. The solution-specific tools and techniques should solve more specific issues, and therefore, the unit of observations identified should reveal what these solution specific tools and techniques are offering and able to solve. Figure 3.12 is a chart of all the units of observations in the solution-specific domain. By nature, what a tool observes is what it seeks to solve. Therefore, by identifying the units of observations relating to the challenges, there should be a connection that can be assessed by means of an AHP, which will be introduced in the next chapter.

## 3.10 Conclusion: Chapter 3

The philosophical approach of pragmatism emphasises the importance of understanding the practices associated with the research (Saunders, Lewis and Thornhill, 2009). Therefore, capturing, categorising and analysing the approaches closely follows the pragmatic philosophy. This chapter was structured around a few objectives. An investigation of the current tools and techniques for urban planning from the last 8 years was contained in the tools and techniques landscape. Thereafter, each of the tools and techniques were allocated to various categories that would assist urban planning decision making. Lastly, the tools and techniques specific to sustainability practices for further assessment in the requirements specification were presented. The previous chapter had identified three prevalent unbiased sustainable urban planning challenges: (i) urbanisation, (ii) urban sprawl and (iii) population growth. The next step is to connect these challenges with the solution-specific approaches found in this chapter. From the collaborative process of connecting the challenges and approaches, a gap will emerge, and the requirements specification will be drawn up to address the challenges alongside the current approaches available in current practice.

Chapter 4 will focus on a MCDA where the urban system elements and SDG are used as the criteria to differentiate the tools and techniques. The MCDA approach will be an analytical hierarchy process because the tools and techniques can be defined by the urban system elements and SDG. The tools and techniques will then be comparable in the research product to assist the urban planners to use the best tools and techniques for their projects.

# Chapter 4: Multi-criteria decision analysis

This chapter sets out to accomplish objective RO2, (ii), as defined in Section 1.3, i.e., identify connections with the challenges addressed in the tools and techniques landscape using a multi-criteria decision analysis (MCDA). This chapter will further develop an understanding of the three prevalent unbiased challenges found in Chapter 2: (i) urbanisation, (ii) urban sprawl and (iii) population growth, in order to prepare the requirements specification. It is evident that there are similarities between these three challenges. And therefore, this chapter reveals the connection with the identified solution-specific oriented approaches found in Chapter 3, using a MCDA approach. The solution-specific tools and techniques embody the sustainable urban planning and implementation requirements indicated in the aim of the study. After which, the results of the MCDA will contribute to generate the requirements specification.

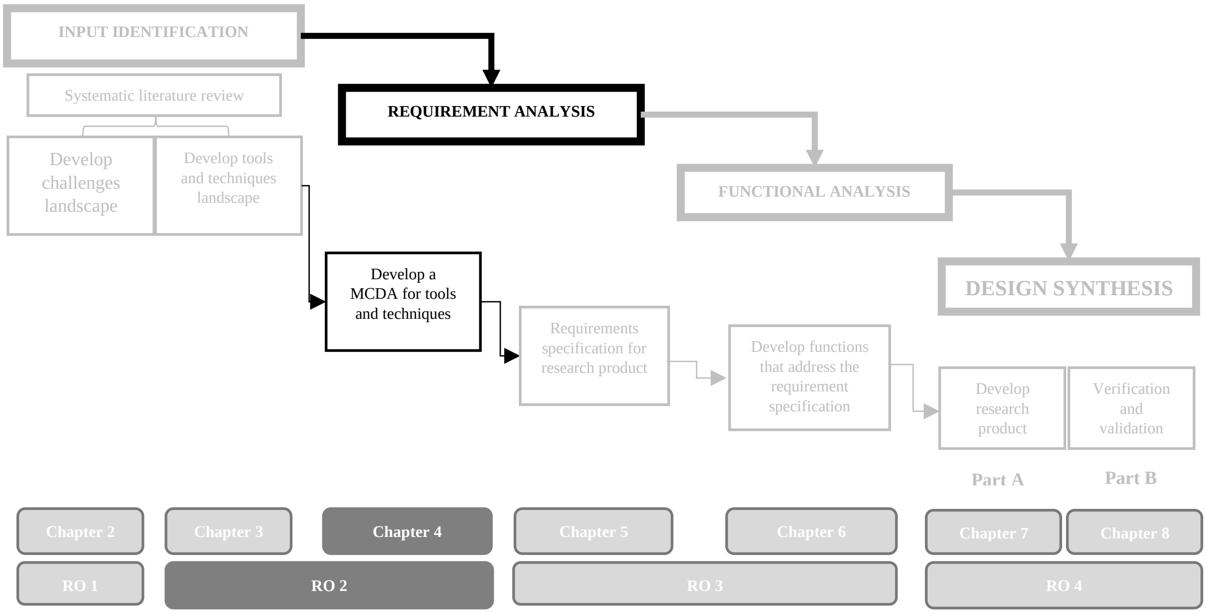



*Figure 4.1: Thesis schematic (Chapter 4)*

The thesis schematic for Chapter 4 summarises the content of this chapter, which will be discussing the MCDA and how it will connect the challenges with urban system elements and SDGs with the solution-specific tools and techniques. Finally, the tools and techniques that are appropriate and suitable for addressing each sustainable urban planning challenge will be identified.

## 4.1 Multi-criteria decision analysis methodology

The purpose of this chapter is to prepare a requirements identification, which is listed as the second phase in the systems engineering approach (Section 5.1). The output will identify the requirements specification needed for the functional analysis, which is the third phase of the systems engineering approach. Identifying the requirements necessary for development of a solution needs comparable assessment of the inputs. To achieve a high-level assessment of the different tools and techniques, a quantifiable approach was necessary. The tools and techniques have different criteria that makes them unique and capable of transforming urban planning challenges into sustainable solutions. However, the 70 solution-specific tools and techniques identified in Chapter 3 need to be assessed and compared. These comparisons will also occur in the research product to provide strategies that the users can implement in their urban planning projects. Therefore, the research requires an approach that can handle various conditions that identify each tool or technique to output a result that a computer can differentiate between each tool or technique.

Multi-criteria decision analysis (MDCA) can be used to evaluate integrated sustainability problems (Wang *et al.*, 2009). MDCA is a functional support approach suitable for highlighting conflicting objectives and multiple interests, such as those encountered in large biophysical and socio-economic systems such as a city (Wang *et al.*, 2009). A common use of MCDA methods is to evaluate alternatives based on several criteria using systematic investigation that overcomes the constraints of unstructured individual or group decision-making (Kiker et al., 2005). For this analysis, the urban system and SDGs need to connect to the challenges with the tools and techniques.

An MCDA was the right choice for this study, as it offered a process that analysed and managed data to facilitate decision making (Shummadtayar, Hokao and Iamtrakul, 2013). In the realm of sustainable urban planning, there are many factors at play. These factors have been identified in the SLR of Chapter 1. The research study has already uncovered the prominent challenges found in developing countries. Furthermore, two criteria under investigation for comparison are the urban system elements and the SDGs. In Chapter 3, the tools and techniques underwent a lengthy categorisation process in which their traits were summarised. The purpose of the chapter is use the MCDA the relevant criteria for the research product.

Currently, the urban system elements and SDGs are defined in words, and are thus difficult to compare to one another without defining them numerically. The aim of the MCDA is to create an easier method of comparing the tools and techniques. Each solution-specific tool and technique will thus be assessed by the MCDA, and each criterion associated with a tool or technique is allocated a set value, thus making it possible to compare them. The comparisons will also quantifiably differentiate each tool and technique. Thereafter, the values of each criterion for a tool or technique can be added up, thus forming a score. These scores can then be evaluated under different conditions that will be inputs from the user of the research product.

The Analytical Hierarchy Process (AHP) is capable of configuring feasible outcomes for the various criteria to enable comparisons between them (Shummadtayar, Hokao and Iamtrakul, 2013), along with a weighting method that creates relative weights, which assists in creating a normalising scale for the scores. The AHP for this assessment will occur twice, i.e., once for the urban system elements and again for the SDGs. Another method that was investigated was the best/worst method. Initial investigations were done into both of these methods to determine their consistency by using the urban system elements and the SDGs as variables.

An assessment using the two methods was conducted together with the Director of the Centre for Statistical Consultation at the University of Stellenbosch, to verify the consistencies. The results neither verified nor denied either one to be conclusively more consistent without receiving more input from subject matter experts (SMEs) in the field of sustainable urban planning. The best/worst method would be more accurate if it had used more input to generate values for overall comparisons. This would allow for less bias and ensure more consistency in the results. However, comparing the importance of one urban element or SDG to one another can also be biased without the proper context. For this study, therefore, it was concluded that an AHP method would yield the same consistency with less input. Therefore, in order to implement the MCDA, an AHP will be conducted to differentiate between the different tools and techniques, thereby ensuring quantifiable output that generates specific numerical values, which will allow the research product to optimise the best strategy for the user.

### 4.1.1 Analytical hierarchy process approach

This section goes into more detail regarding the approach used by the AHP. First, laying out the steps that will take place. Then, where the inputs will be drawn from. Lastly, the output of what the AHP method will generate and contribute to the research.

The AHP approach follows 4 steps:

i. Definition of the criteria;
ii. Pairwise comparisons;
iii. Weighting method; and
iv. Calculation of the scores.

The AHP connects the tools and techniques to the elements of an urban system and SDGs. This allows for quantifiable data to compare the tools and techniques with each other and achieve different outputs along variable inputs. The quantifiable data will be compiled in the triple bottom line table, which is the output of the AHP. The three identifiers (challenges landscape, tools and techniques landscape and triple bottom line table in Table 4.8) are used as the inputs to generate the requirements specification for developing a research product that will allow stakeholders to solve challenges relating to sustainable urban planning in developing countries.

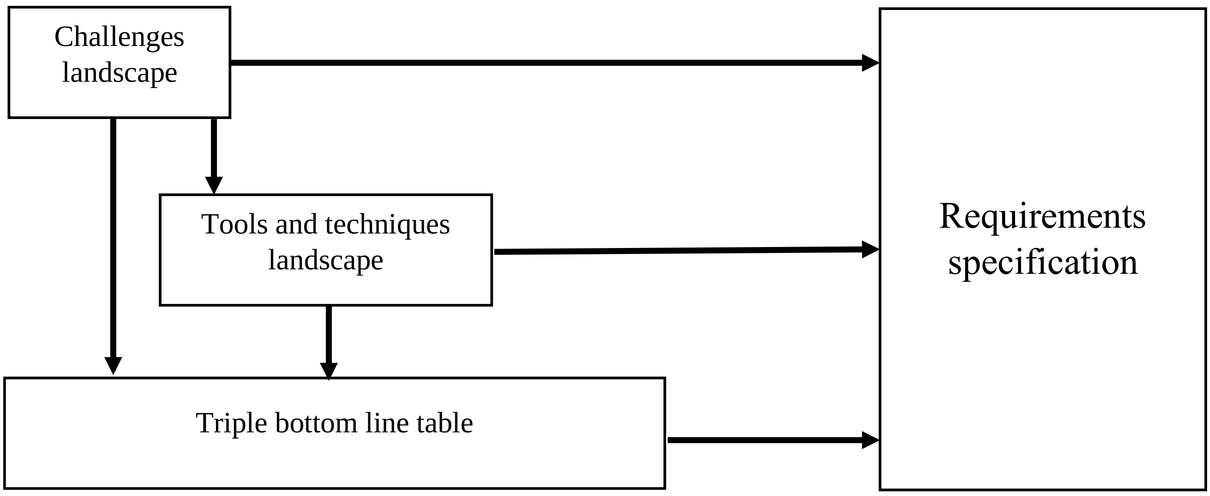



*Figure 4.2: Three identifiers for the requirements specification*

Figure 4.2 illustrates how the information passed between the individual identifiers until they reach the requirements specification. The data gathered from the SLR formed the challenges landscape and the tools and techniques landscape, and the knowledge gained from these two landscapes was fed into the AHP, which produced the triple bottom line table in Table 4.8.

## 4.2 Elements of tools and techniques and SDGs

The 70 tools and techniques, shown in Table 3.2, were further defined using the urban system elements and the SDGs, in Sections 2.5.1 and 2.5.2 respectively. By defining the tools and techniques in this manner, they become quantifiable when using a pairwise comparison method, such as the AHP. The pairwise comparison is explained in Section 4.3. Solution-specific tools and techniques regarding urban system elements and SDGs are summarised in Table 4.1 and Table 4.2 respectively.

*Table 4.1: Defining tools and techniques in terms of the city elements*

| Tool or Technique | Urban system element(s) | Tool or Technique | Urban system element(s) |
|---|---|---|---|
| Smart sustainable city (SSC) | Commercial, Industrial, Community, Infrastructure | Vertical farming | Commercial, Community, Biophysical, Infrastructure |
| Successful neighbourhood model (SNM) | Residential, Community, Recreation, Socio-economic | Building integrated agriculture (BIA) | Commercial, Community, Biophysical, Infrastructure, |
| Smart growth | Recreation, Transport, Socio-economic | Eco-effective architecture | Commercial, Community, Biophysical, Infrastructure |
| Systemic conceptual framework for compact and green cities | Residential, Business, Biophysical, Recreation, Transport, Socio-economic | Sustainable water management | Industrial, Infrastructure, Biophysical, Socio-economic |
| Smart-compact-green city framework | Residential, Business, Biophysical, Recreation, Transport, Socio-economic | Green revolution | Commercial, Community, Biophysical, Socio-economic |
| GIS analysis | Residential, Commercial, Business, Recreation, Infrastructure | Blue revolution | Commercial, Community, Biophysical, Infrastructure |
| Landscape design | Recreation, Biophysical, Infrastructure | Water policy | Biophysical, Infrastructure, Industrial |
| Land-use regulation | Residential, Commercial, Business, Community, Recreation, | SWAGMAN – a water management tool | Commercial, Biophysical, Infrastructure |
| Sustainable and green infrastructure | Residential, Commercial, Business, Community, Biophysical, Infrastructure | New urbanism | Residential, Commercial, Business, Recreation, Socio-economic |
| Green Road Concept | Transport | Smart growth network (SGN) | Recreation, Transport, Socio-economic |
| Eco-Town | Commercial, Industrial, Community, Biophysical, Socio-economic | Leadership in energy and environmental design (LEED) | Commercial, Business, Infrastructure, Biophysical |
| Smart development | Residential, Commercial, Community, Recreation, Socio-economic | Water-sensitive urban design (WSUD) | Residential, Commercial, Biophysical, Infrastructure, Transport |
| Retrofitting | Residential, Commercial, Business, Industrial, Community, Infrastructure | Corridor development | Residential, Commercial, Business, Infrastructure, Transport |
| Solweig – a climate design tool | Industrial, Infrastructure, Transport | Non-transport policies | Residential, Commercial, Business, Industrial, Co-mmunity, Infrastructure |
| Parallelized Large-eddy Simulation Model (PALM) | Infrastructure, Socio-economic, | Transit-oriented development | Residential, Commercial, Business, Transport |

| | | | |
|---|---|---|---|
| Estidama | Commercial, Business, Infrastructure, Biophysical | Planning for less travel | Residential, Commercial, Business, Industrial, Community, Infrastructure |
| Conceptual design matrix for sustainable urban form | Residential, Commercial, Community, Recreation | Mixed-use strategy | Residential, Commercial, Business, Industrial, Community, Infrastructure |
| Neotraditional development and urban containment | Residential, Commercial, Business, Biophysical, Transport, Socio-economic | Adaptation planning | Industrial, Infrastructure, Transport, Socio-economic |
| New urban agenda (NUA) | Community, Infrastructure, Recreation, Biophysical, Socio-economic | City-disasters nexus | Residential, Commercial, Community, Business, Infrastructure, Socio-economic |
| Floor area ratios (FAR) | Residential, Commercial, Community | Disaster resilient city | Residential, Commercial, Community, Office, Infrastructure, Socio-economic |
| Energy landscapes | Residential, Commercial, Community, Industrial, Infrastructure | The green new deal | Commercial, Community, Biophysical, |
| Sustainable urbanism | Community, Transport, Infrastructure, Recreation, Socio-economic | Eco-cities | Community, Transport, Infrastructure, Recreation, Biophysical, Socio-economic |
| Anti-fragility | Industrial, Infrastructure, Transport, Socio-economic | Green-capitalism | Commercial, Industrial, Socio-economic |
| Green urbanism | Commercial, Community, Industrial, Biophysical, Transport | Township and village enterprises (TVEs) | Commercial, Community, Biophysical, Industrial, Transport, Socio-economic |
| Compact city | Residential, Commercial, Business, Community, Recreation, Transport | Climate planning | Industrial, Infrastructure, Transport, Socio-economic |
| Trinity of cities sustainability | Residential, Commercial, Business, Community, Industrial, Transport, Socio-economic | Green economic investment | Commercial, Community, Industrial, Biophysical, Infrastructure, Socio-economic |
| Sustainable urbanisation framework | Residential, Commercial, Community, Industrial, Infrastructure, Transport | Bus rapid transit (BRT) | Transport |
| Compact coefficient of urban area (CCUA) | Residential, Commercial, Business, Community, Recreation, Transport | Local governments for sustainability's | Commercial, Community, Industrial, Transport, Socio-economic |
| Green belt | Residential, Biophysical, Transport, Socio-economic | Peri-urban agriculture | Commercial, Community, Biophysical, Transport |
| Polycentric networks | Biophysical, Infrastructure, Transport, | Green city design | Residential, Commercial, Industrial, Infrastructure, Transport |
| Urban agriculture | Commercial, Community, Biophysical, Infrastructure | Urban green space | Residential, Community, Recreation, Biophysical, Socio-economic |
| Green urban architecture | Commercial, Community, Biophysical, Infrastructure | Landscape ecology | Recreation, Biophysical, Infrastructure |
| Z-Farming | Residential, Community, Commercial, Biophysical, Infrastructure | 3Rs (reducing, reusing, and recycling) | Commercial, Community, Biophysical, Socio-economic |
| Edible city | Commercial, Community, Biophysical, Infrastructure | Roof gardening | Residential, Community, Commercial, Biophysical |
| Brownfield development | Residential, Commercial, Business, Industrial, Community, Infrastructure | Concentric circles | Residential, Commercial, Business, Community, Recreation, Transport |

*Table 4.2: Defining tools and techniques in terms of the sustainable development goals*

| Tool or Technique | SDGs | Tool or Technique | SDGs |
|---|---|---|---|
| Smart sustainable city (SSC) | 7, 9, 11, 12, 13 | Vertical farming | 2, 3, 6, 8, 12, 13, 15 |
| Successful neighbourhood model (SNM) | 3, 11, 12 | Building integrated agriculture (BIA) | 2, 3, 6, 8, 12, 13, 15 |
| Smart growth | 3, 11, 12, 13 | Eco-effective architecture | 2, 3, 6, 11, 12, 13 |
| Systemic conceptual framework for compact and green cities | 11, 12, 13, 15 | Sustainable water management | 6, 12, 13 |
| Smart-compact-green city framework | 11, 12, 13, 15 | Green revolution | 2, 3, 12, 13, 15 |
| GIS analysis | 8, 9, 12 | Blue revolution | 6, 12, 13 |
| Landscape design | 2, 6, 9, 11, 12, 13, 15 | Water policy | 6, 12, 13 |
| Land-use regulation | 9, 10, 11, 12, 13 | SWAGMAN – a water management tool | 6, 12, 13 |
| Sustainable and green infrastructure | 7, 11, 12, 13, 15 | New urbanism | 3, 11, 12, 13 |
| Green road Concept | 9, 12, 13, 15 | Smart growth network (SGN) | 3, 11, 13 |
| Eco-Town | 9, 11, 12, 13, 15 | Leadership in energy and environmental design (LEED) | 7, 11, 12, 13 |
| Smart development | 3, 4, 5, 6, 7, 11, 12 | Water-sensitive urban design (WSUD) | 3, 6, 11, 12, 13 |
| Retrofitting | 9, 12, 13 | Corridor development | 11, 12, 13 |
| Solweig – a climate design tool | 9, 11, 13 | Non-transport policies | 9, 11, 12, 13 |
| Parallelized Large-eddy Simulation Model (PALM) | 9, 11, 13 | Transit-oriented development | 11, 12, 13 |
| Estidama | 7, 11, 12, 13 | Planning for less travel | 9, 11, 12, 13 |
| Conceptual design matrix for sustainable urban form | 11, 12, 13 | Mixed-use strategy | 9, 11, 12, 13 |
| Neotraditional development and urban containment | 2, 3, 11, 12, 13 | Adaptation planning | 7, 9, 11, 12, 13 |
| New urban agenda (NUA) | 3, 4, 6, 7, 8, 10, 11, 12, 13, 16 | City-disasters nexus | 11, 13 |
| Floor area ratios (FAR) | 3, 11, 12, 13 | Disaster resilient city | 11, 13 |
| Energy landscapes | 7, 9, 12 | The green new deal | 7, 9, 11, 12, 13, 15 |
| Sustainable urbanism | 3, 7, 11, 12, 13 | Eco-cities | 11, 12, 13, 15 |
| Anti-fragility | 7, 9, 11, 13 | Green-capitalism | 7, 8, 9, 11, 12, 13, 15 |
| Green urbanism | 11, 12, 13, 15 | Township and village enterprises (TVEs) | 1, 2, 8, 12 |
| Compact city | 3, 11, 12, 13 | Climate planning | 7, 9, 11, 12, 13 |
| Sustainable urbanisation framework | 9, 11, 12, 13 | Green economic investment | 7, 8, 11, 12, 13, 15 |
| Trinity of cities sustainability | 3, 9, 11, 12, 13 | Bus rapid transit (BRT) | 11, 12 |
| Compact coefficient of urban area (CCUA) | 3, 11, 12, 13 | Local governments for sustainability's | 4, 5, 8, 9, 10, 11, 13, 16 |
| Green belt | 2, 12, 13, 15 | Peri-urban agriculture (UPA) | 2, 3, 6, 8, 12, 13, 15 |
| Polycentric networks | 7, 9, 11, 12, 13 | Green city design | 11, 12, 13, 15 |
| Urban agriculture | 2, 3, 6, 8, 12, 13, 15 | Urban green space | 12, 13, 15 |
| Green urban architecture | 3, 6, 12, 13, 15 | Landscape ecology | 12, 13, 15 |
| Z-Farming | 2, 3, 6, 12, 13, 15 | 3Rs (reducing, reusing, and recycling) | 8, 12, 13, 15 |
| Edible city | 2, 3, 6, 8, 12, 13, 15 | Roof gardening | 2, 3, 6, 8, 12, 13, 15 |
| Brownfield development | 9, 12 | Concentric circles | 3, 11, 12, 13 |

Using Table 2.3, the 70 solution-specific tools and techniques in Table 4.1 were associated with urban system elements that describe where and how the tool or technique functions. The same approach was used for Table 4.2. Using the SDGs in Figure 2.6, the 70 solution-specific tools and techniques were associated with the SDGs. The two new expressive factors (Table 4.1 and Table 4.2) will be used to compare the criteria for the different tools and techniques. An AHP will be used to generate a score so that the tools and techniques have quantifiable differences when running comparisons under different conditions.

## 4.3 Pairwise comparison

Pairwise comparison was an important step in the AHP (Saaty, 1990). To compare the relevant criteria, it was necessary to ask: Which one of these two criteria is more important, and how much more important? A scale developed by Thomas Saaty, represented in Table 4.3, was used to compare two criteria in a pairwise comparison to quantify the analysis.

*Table 4.3: Pairwise comparison method*

| **The Fundamental Scale for Pairwise Comparisons** | | |
|---|---|---|
| **Intensity of importance** | **Definition** | **Explanation** |
| 1 | Equal importance | Two elements contribute equally to the objective |
| 3 | Moderate importance | Experience and judgement strongly favour one element over another |
| 5 | Strong importance | The evidence favouring one element over another is of the highest possible order of affirmation |

First, the urban system elements in Table 2.3 were compared to one another. This comparison was vital to the study. Using the sustainable urban planning perspective to make these pairwise comparisons establishes reasonable cause for their relative importance. This comparison was then used as input by the weighting method in Equation 1. Using the scale defined in Table 4.3, the next step was to compare the elements to each other. The assessment for the urban system elements is shown in Table 4.4.

*Table 4.4: Pairwise comparisons of urban system elements*

| A=j \ B=i | Residential | Commercial | Business | Industrial | Community | Recreational | Biophysical assets | Infrastructure | Transport network | Socio-economic |
|---|---|---|---|---|---|---|---|---|---|---|
| **Residential** | | 1 | 5 | 3 | 1 | 5 | 3 | 1 | 1 | 3 |
| **Commercial** | 1 | | 3 | 1 | | 5 | 1 | | | 1 |
| **Business** | | | | 1 | | 1 | | | | |
| **Industrial** | | 1 | 1 | | | 1 | | | | |
| **Community** | 1 | 3 | 5 | 5 | | 1 | 3 | 1 | 3 | 1 |
| **Recreational** | | | 1 | 1 | 1 | | | | | 1 |
| **Biophysical assets** | | 1 | 3 | 5 | | 5 | | 3 | 5 | 3 |
| **Infrastructure** | 1 | 5 | 5 | 5 | 1 | 3 | | | 1 | |
| **Transport network** | 1 | 5 | 5 | 3 | | 3 | | 1 | | 1 |
| **Socio-economic activities** | | 1 | 3 | 5 | 1 | 1 | | 3 | 1 | |

The pairwise comparisons for the SDGs are associated with the context of an urban system. The purpose of this comparison is to identify the goals that are specific to defining sustainable urban planning in a developing country context. Table 4.5 represents the comparisons with each of the SDGs.

*Table 4.5: Pairwise comparisons of sustainable development goals*

| A=j \ B=i | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | | 1 | 5 | 5 | 5 | 3 | 1 | 3 | 1 | 1 | | | 5 | 5 | 3 | 3 | 5 |
| **2** | 1 | | 5 | 5 | 5 | 3 | 1 | 3 | 3 | 3 | | | 5 | 3 | 3 | 3 | 5 |
| **3** | | | | 3 | 1 | 1 | | 3 | 3 | 1 | | | 1 | 3 | 1 | 1 | 3 |
| **4** | | | | | 3 | | | 1 | 1 | 1 | | | 1 | 3 | 1 | 1 | 3 |
| **5** | | | 1 | | | | | 1 | 1 | 1 | | | | 3 | 1 | 1 | 5 |
| **6** | | | 1 | 3 | 3 | | 3 | 5 | 3 | 3 | | 1 | 1 | 1 | 1 | 3 | 5 |
| **7** | 1 | 1 | 3 | 3 | 3 | | | 3 | 1 | 3 | 1 | | 3 | 3 | 1 | 3 | 5 |
| **8** | | 3 | | 1 | 1 | | | | | 1 | | | | | | | 1 |
| **9** | 1 | | | 1 | 1 | | 1 | 3 | | 1 | | | | 1 | | | 3 |
| **10** | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | | 1 | 3 | 1 | 1 | 5 |
| **11** | 3 | 3 | 3 | 3 | 5 | 3 | 1 | 5 | 3 | 3 | | 3 | 1 | 3 | 1 | 3 | 5 |
| **12** | 3 | 3 | 3 | 3 | 5 | 1 | 3 | 5 | 3 | 3 | | | 1 | 3 | 1 | 3 | 5 |
| **13** | | | 1 | 1 | 3 | 1 | | 5 | 3 | 1 | 1 | 1 | | 3 | 3 | 3 | 3 |
| **14** | | | | | | 1 | | 3 | 1 | | | | | | | | 3 |
| **15** | | | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | | 3 | | 3 | 5 |
| **16** | | | 1 | 1 | 1 | | | 3 | 3 | 1 | | | | 3 | | | 5 |
| **17** | | | | | | | | 1 | | | | | | | | | |

The aim of the AHP study was to compare the tools and techniques in order to decide which of them can best be used in the research product. These pairwise comparisons of the urban system elements and SDGs create conditions that the user will use as input into the research product; this will allow the research product to output the strategy that is best suited for the user. These conditions and strategies will be unpacked in the requirements specification in Chapter 5 and further elaborated on in the functional analysis in Chapter 6.

## 4.4 Weighting method

The principle of the least square method (LSM) is that one criterion carries less importance for the results, and that it can thus be ignored when the performances of alternatives are almost the same, although these criteria are vital in evaluation do you mean 'it is vital to evaluate all of them (Wang *et al.*, 2009). Let:

$$Sj = \sqrt{\frac{1}{m} * \sum_{i=1}^{m} \left(x_{ij} - \bar{x}_j\right)^2} \qquad (j = 1;\ 2;\ \dots;\ n) \qquad (1)$$

Where Xij is the i-th sample of the j-th criteria, i = 1, 2, . . ., m, and $\bar{x}_j = (\frac{1}{\mathrm{m}} * \sum_{i=1}^{m} x_j)$. This method was used to elicit the selected weights using the pairwise comparisons found in Table 4.4 and Table 4.5 (the m alternative in the selected n criteria form to the new group decision matrix and then the calculated standard deviation in Eq.$Sj = \sqrt{\frac{1}{m} * \sum_{i=1}^{m} \left(x_{ij} - \bar{x}_j\right)^2} \qquad (j = 1;\ 2;\ \dots;\ n)$

(1) again is normalized to get the weights). "*An elementary goal objective approach may rank the alternatives in relation to the total number of performance thresholds met or surpassed*" (Kiker *et al.*, 2005). Using the LSM to capture the weights of all the elements and SDGs, a quantifiable number that represents each element and SDG is calculated and averaged in Table 4.6.

The next step in the MCDA is to use the values from the AHP and generate a score that differentiates the tools and techniques. The averaged AHP score is used to calculate the triple bottom line score. The triple bottom line score is calculated by dividing the AHP score using a new scale in Table 4.7. Subjecting the new scale to the AHP values and implementing a triple bottom line score allows for the research product to identify that the tool or technique contributes to a social, environmental or economic impact and adjusts for the quantity of such impact. This is possible due to the importance shown from defining the tools or techniques regarding urban system elements and SDGs, and the pairwise comparisons. This scale is further explained in Section 4.5.

*Table 4.6: Overall scores of the tools and techniques*

| Tool or Technique | Elements | Goals | Aggregate | Tool or Technique | Elements | Goals | Aggregate |
|---|---|---|---|---|---|---|---|
| Smart sustainable city (SSC) | 0.416 | 0.329 | 0,373 | Vertical farming | 0.464 | 0.453 | 0,459 |
| Successful neighbourhood model (SNM) | 0.419 | 0.204 | 0,312 | Building integrated agriculture (BIA) | 0.464 | 0.453 | 0,459 |
| Smart growth | 0.293 | 0.274 | 0,283 | Eco-effective architecture | 0.464 | 0.430 | 0,447 |
| Systemic conceptual framework for compact and green cities | 0.584 | 0.294 | 0,439 | Sustainable water management | 0.413 | 0.224 | 0,319 |
| Smart-compact-green city framework | 0.563 | 0.294 | 0,373 | Green revolution | 0.438 | 0.347 | 0,393 |
| GIS analysis | 0.483 | 0.142 | 0,312 | Blue revolution | 0.464 | 0.224 | 0,344 |
| Landscape design | 0.322 | 0.488 | 0,405 | Water policy | 0.312 | 0.130 | 0,221 |
| Land-use regulation | 0.474 | 0.324 | 0,399 | SWAGMAN | 0.363 | 0.125 | 0,244 |
| Sustainable and green infrastructure | 0.639 | 0.362 | 0,501 | New urbanism | 0.456 | 0.274 | 0,365 |
| Green road concept | 0.112 | 0.256 | 0,184 | Smart growth network (SGN) | 0.293 | 0.198 | 0,245 |
| Eco-Town | 0.506 | 0.332 | 0,419 | Leadership in energy and environmental design (LEED) | 0.400 | 0.291 | 0,346 |
| Smart development | 0.520 | 0.461 | 0,491 | Water-sensitive urban design (WSUD) | 0.576 | 0.352 | 0,464 |
| Retrofitting | 0.591 | 0.184 | 0,388 | Corridor development | 0.516 | 0.222 | 0,369 |
| SOLWEIG | 0.308 | 0.184 | 0,246 | Non-transport policies | 0.591 | 0.261 | 0,426 |
| PALM | 0.229 | 0.184 | 0,207 | Transit-oriented development | 0.388 | 0.222 | 0,305 |
| ESTIDAMA | 0.400 | 0.291 | 0,346 | Planning for less travel | 0.591 | 0.261 | 0,426 |
| Conceptual design matrix for sustainable urban form | 0.419 | 0.222 | 0,321 | Mixed-use strategy | 0.591 | 0.261 | 0,426 |
| Neotraditional development and urban containment | 0.606 | 0.352 | 0,479 | Adaptation planning | 0.410 | 0.329 | 0,369 |
| New urban agenda (NUA) | 0.543 | 0.617 | 0,580 | City-disasters nexus | 0.625 | 0.146 | 0,386 |
| Floor area ratios (FAR) | 0.340 | 0.274 | 0,307 | Disaster resilient city | 0.625 | 0.141 | 0,383 |
| Energy landscapes | 0.536 | 0.183 | 0,359 | The green new deal | 0.36 | 0.428 | 0,382 |
| Sustainable urbanism | 0.540 | 0.342 | 0,441 | Eco-cities | 0.656 | 0.294 | 0,475 |
| Anti-fragility | 0.410 | 0.253 | 0,331 | Green-capitalism | 0.271 | 0.428 | 0,349 |
| Green urbanism | 0.517 | 0.294 | 0,405 | Township and village enterprises (TVEs) | 0.618 | 0.279 | 0,449 |
| Compact city | 0.587 | 0.274 | 0,430 | Climate planning | 0.410 | 0.329 | 0,369 |
| Sustainable urbanisation framework | 0.648 | 0.261 | 0,469 | Green economic investment | 0.634 | 0.390 | 0,512 |
| Trinity of cities sustainability | 0.678 | 0.312 | 0,480 | Bus rapid transit (BRT) | 0.112 | 0.152 | 0,132 |
| Compact coefficient of urban area (CCUA) | 0.587 | 0.274 | 0,430 | Local governments for sustainability's (ICLEI's) | 0.502 | 0.448 | 0,475 |
| Green belt | 0.449 | 0.296 | 0,373 | Peri-urban agriculture (UPA) | 0.449 | 0.453 | 0,451 |
| Polycentric networks | 0.356 | 0.329 | 0,342 | Green city design | 0.528 | 0.294 | 0,411 |
| Urban agriculture | 0.464 | 0.453 | 0,459 | Urban green space | 0.535 | 0.217 | 0,376 |
| Green urban architecture | 0.464 | 0.347 | 0,405 | Landscape ecology | 0.322 | 0.102 | 0,212 |
| Z-Farming | 0.583 | 0.425 | 0,504 | 3Rs (reducing, reusing, and recycling) | 0.438 | 0.245 | 0,342 |
| Edible city | 0.464 | 0.453 | 0,459 | Roof gardening | 0.456 | 0.453 | 0,454 |
| Brownfield development | 0.591 | 0.114 | 0,353 | Concentric circles | 0.587 | 0.274 | 0,430 |

It must be first noted that there is bias attached to the new urban agenda. This approach to sustainable urban planning is directly associated with the sustainable development goals. Therefore, they correlate very well regarding that criterion achieving a very high score.

## 4.5 Calculating the triple bottom line score

The stated aim of this study is to contribute to a balance between the social, environmental and economic stability within a city system. The assessment of the AHP allows an additional scale to differentiate between the tools and techniques. With the assistance of Table 4.7 below, points are spread out according to the triple bottom line score achieved.

*Table 4.7: Additional points awarded for the triple bottom line score (Source: Author)*

| AHP SCALE | |
|---|---|
| **>0,15** | 3 |
| **>0,2** | 4 |
| **>0,25** | 5 |
| **>0,3** | 6 |
| **>0,35** | 7 |
| **>0,4** | 8 |
| **>0,45** | 9 |
| **>0,5** | 10 |

The scores will be spread out among the Triple bottom line fundamentals: (i) Social Equality, (ii) Local Environmental, and (iii) Sustainable Economy. Table 4.8 tallies up the scores spread out among these three, according to the AHP assessment. For example, if an AHP score of 0.373 was attained by the Smart Sustainable City (SSC) tool, then, reading from Table 4.7, this means that the SSC tool is given 7 points to assign to the three sustainable fundamentals. These scores will be used in the functional analysis phase of the systems engineering approach in determining the intervention strategies available for the research product.

*Table 4.8: Triple bottom line scores*

| Tools and Techniques | AHP | Social | Environmental | Economic | Total |
|---|---|---|---|---|---|
| **Smart Sustainable City (SSC)** | **0,373** | **1** | **3** | **3** | **7** |
| **Successful Neighbourhood Model (SNM)** | **0,312** | **2** | **2** | **1** | **5** |
| **Smart growth** | **0,283** | **1** | **2** | **2** | **5** |
| **Systemic conceptual framework for compact and green cities** | **0,439** | **1** | **4** | **3** | **8** |
| **Smart-compact-green city framework** | **0,373** | **1** | **3** | **3** | **7** |
| **GIS analysis** | **0,312** | **0** | **2** | **4** | **6** |
| **Landscape design** | **0,405** | **1** | **4** | **3** | **8** |
| **Land-use regulation** | **0,399** | **2** | **2** | **3** | **7** |
| **Sustainable and green infrastructure** | **0,501** | **2** | **5** | **3** | **10** |
| **Green Road Concept** | **0,184** | **0** | **2** | **1** | **3** |
| **Eco-Town** | **0,419** | **2** | **4** | **2** | **8** |

| | | | | | |
|---|---|---|---|---|---|
| **Smart development** | **0,491** | **3** | **3** | **3** | **9** |
| **Retrofitting** | **0,388** | **0** | **3** | **4** | **7** |
| **SOLWEIG** | **0,246** | **0** | **2** | **2** | **4** |
| **PALM** | **0,207** | **0** | **2** | **1** | **3** |
| **ESTIDAMA** | **0,346** | **1** | **3** | **2** | **6** |
| **Conceptual Design Matrix for Sustainable Urban Form** | **0,321** | **1** | **3** | **2** | **6** |
| **Neotraditional Development and Urban Containment** | **0,479** | **2** | **4** | **3** | **9** |
| **New Urban Agenda** | **0,580** | **5** | **3** | **2** | **10** |
| **Floor area ratios (FAR)** | **0,307** | **0** | **3** | **3** | **6** |
| **Energy landscapes** | **0,359** | **1** | **3** | **3** | **7** |
| **Sustainable urbanism** | **0,441** | **3** | **3** | **2** | **8** |
| **Anti-fragility** | **0,331** | **2** | **0** | **4** | **6** |
| **Green urbanism** | **0,405** | **2** | **4** | **2** | **8** |
| **Compact city** | **0,430** | **2** | **3** | **3** | **8** |
| **Sustainable urbanisation framework** | **0,469** | **3** | **3** | **3** | **9** |
| **Trinity of cities sustainability** | **0,480** | **2** | **3** | **4** | **9** |
| **Compact coefficient of urban area (CCUA)** | **0,430** | **2** | **3** | **3** | **8** |
| **Green belt** | **0,373** | **2** | **4** | **1** | **7** |
| **Polycentric networks** | **0,342** | **0** | **2** | **4** | **6** |
| **Urban agriculture** | **0,459** | **1** | **4** | **4** | **9** |
| **Green urban architecture** | **0,405** | **2** | **3** | **3** | **8** |
| **Z-Farming** | **0,504** | **2** | **4** | **4** | **10** |
| **Edible city** | **0,459** | **1** | **4** | **4** | **9** |
| **Brownfield development** | **0,353** | **0** | **3** | **4** | **7** |
| **Vertical farming** | **0,459** | **1** | **4** | **4** | **9** |
| **Building integrated agriculture (BIA)** | **0,459** | **1** | **4** | **4** | **9** |
| **Eco-effective architecture** | **0,447** | **2** | **3** | **3** | **8** |
| **Sustainable Water Management** | **0,319** | **1** | **3** | **2** | **6** |
| **Green Revolution** | **0,393** | **1** | **3** | **3** | **7** |
| **Blue Revolution** | **0,344** | **1** | **3** | **2** | **6** |
| **Water policy** | **0,221** | **0** | **3** | **1** | **4** |
| **SWAGMAN** | **0,244** | **0** | **3** | **1** | **4** |
| **New urbanism** | **0,365** | **2** | **2** | **3** | **7** |
| **Smart Growth Network (SGN)** | **0,245** | **2** | **2** | **1** | **5** |
| **Leadership in Energy and Environmental Design (LEED)** | **0,346** | **1** | **3** | **2** | **6** |
| **Water-sensitive urban design (WSUD)** | **0,464** | **2** | **4** | **3** | **9** |
| **Corridor development** | **0,369** | **1** | **2** | **4** | **7** |
| **Non-transport policies** | **0,426** | **3** | **3** | **2** | **8** |
| **Transit-oriented development** | **0,305** | **1** | **2** | **3** | **6** |
| **Planning for less travel** | **0,426** | **3** | **3** | **2** | **8** |
| **Mixed-use strategy** | **0,426** | **3** | **3** | **2** | **8** |
| **Adaptation planning** | **0,369** | **3** | **1** | **3** | **7** |

| | | | | | |
|---|---|---|---|---|---|
| **City-disasters nexus** | **0,386** | **2** | **0** | **4** | **6** |
| **Disaster resilient city** | **0,383** | **2** | **0** | **4** | **6** |
| **Climate planning** | **0,382** | **3** | **1** | **3** | **7** |
| **The Green New Deal** | **0,475** | **1** | **3** | **5** | **9** |
| **Eco Cities** | **0,349** | **2** | **3** | **2** | **7** |
| **Green-capitalism** | **0,449** | **1** | **3** | **5** | **9** |
| **Township and Village Enterprises (TVEs)** | **0,369** | **4** | **1** | **2** | **7** |
| **Green economic investment** | **0,512** | **1** | **4** | **5** | **10** |
| **Bus rapid transit (BRT)** | **0,132** | **1** | **1** | **1** | **3** |
| **Local Governments for Sustainability's (ICLEI's)** | **0,475** | **5** | **2** | **2** | **9** |
| **Peri-urban agriculture (UPA)** | **0,451** | **1** | **4** | **4** | **9** |
| **Green city design** | **0,411** | **2** | **4** | **2** | **8** |
| **Urban green space** | **0,376** | **2** | **4** | **1** | **7** |
| **Landscape ecology** | **0,212** | **1** | **3** | **0** | **4** |
| **3Rs (Reducing, Reusing, and Recycling)** | **0,342** | **2** | **3** | **1** | **6** |
| **Roof gardening** | **0,454** | **2** | **4** | **3** | **9** |
| **Concentric circles** | **0,430** | **2** | **2** | **4** | **8** |

Scaling the AHP scores into groups separates the tools and techniques further. With the triple bottom line scores calculated, the tools or techniques can be differentiated into their capabilities of contributing towards the three sustainability factors. For example, in the case of a user who requires a project to have an impact on social equality, the research product will identify the New Urban Agenda and the Local Governments for Sustainability, which both have additional social points of 5 (shown in Table 4.8), as tools or techniques that have the best chance to achieve social equality. For more information, the excel spreadsheet can be found in Appendix A.3.

## 4.6 Conclusion: Chapter 4

Combining the problems (i.e. sustainable urban planning challenges) and practices (i.e. tools and techniques) is a significant part of the pragmatic philosophy, which underpins this research (Saunders, Lewis and Thornhill, 2009). Furthermore, connecting the qualitative and quantitative methods is also part of the pragmatic strategy. By assessing each sustainable urban planning challenge according to the elements and the SDGs that they represent, an AHP score was calculated for each tool and technique. Therefore, a change in view identifies which are the highest scores for each sustainable urban planning challenge. The research product will utilise all of the evaluated data generated from the identifiers compiled in Figure 4.2. This collaboration of all the relevant aspects leads to the requirements specification, which necessitates determining all the aspects and features necessary to achieve the stated aim of this research project. All the inputs from the user will generate conditions that will meet the optimal choice for a sustainable strategy for the user. The requirements specification of the decision support framework will be discussed further in Chapter 5 and elaborated on in the functional analysis phase of the systems engineering approach in Chapter 6.

# Chapter 5: Requirements specification

This chapter sets out to accomplish objective RO3, (i), as defined in Section 1.3, i.e., determine the functional requirements, user requirements, design restrictions, attention points and boundary conditions to perform a requirements specification for the research product. Over 200 tools and techniques that have been used in the last decade to address sustainability challenges related to urban planning were extracted from the literature, as discussed in Chapter 3, Section 3.7. From these, a tools and techniques landscape was constructed (Table 3.2), whose purpose was to categorise the large array of tools and techniques into approaches that are specific to sustainable urban planning and that are implementation-oriented. Allocating each tool and technique to several categories requires an in-depth understanding of their intended purpose. The most challenging aspect of developing this tools and techniques landscape was ensuring accuracy and an unbiased approach when classifying them. A systematic approach was thus used in the SLR in order to ensure that all the tools and techniques were identified. Thereafter, they were grouped into well-defined categories (see Section 3.7), and finally, linked to various problem-solving approaches, namely, problem-generic, problem-specific, solution-generic and solution-specific (Section 3.6). Figure 3.6 illustrates how these different types of approaches fit into the problem-solving layout (i.e., tools and techniques that target solutions by delivering holistic and sustainable approaches are categorised as solution-specific). In this way, a set of tools and techniques that address sustainable urban planning challenges was established.

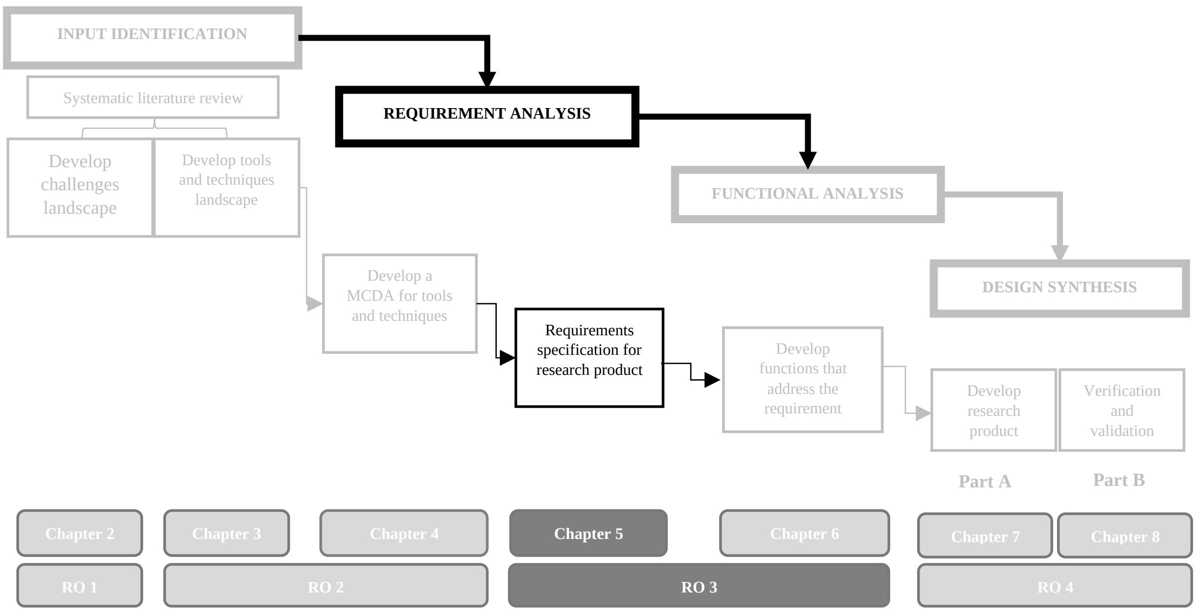



*Figure 5.1: Thesis schematic (Chapter 5)*

The AHP made quantifiable comparisons of the tools and techniques. Using all the evaluated data (discussed in Section 4.5), a requirements specification may be developed to support the development of a solution to address the aim of this research study – which is to contribute towards increasing the successful implementation of urban sustainability and reduce the challenges faced in developing countries. Increasing the sustainability of a city also supports that city's ability to respond and adapt to a wide assortment of problems and unforeseen disasters (Simon, 2013; Wamsler, Brink and Rivera, 2013). Whether it is increasing environmental priority for a project to reduce climate impact or prioritising social equality development to build up communities, this research study should provide clarity with regard to the possibilities and advantages of creating a balanced setting for the future.

The following sections elaborate on the requirement specification procedure of the research product set out in the thesis schematic and the systems engineering approach (see Figure 4.2) to act as a bridge between the requirement analysis and the functional analysis, connecting these by a process of verification by SMEs (see Appendix B.2 and B.3).

Developing an appropriate research product, which is the aim of this study, means that several requirements must be met. Questions will need to be formulated to guide the investigation so that principles of comparative management styles emerge in respect of sustainable urban planning practices in developing countries. The investigation strategy follows a systems engineering approach, which has guided the research so far. Chapter 1 and Chapter 3 covered the input identification, while this chapter analyses the requirements and arrives at a requirements specification. Such a requirements specification can be distinguished according to five requirement types (Huff, Tranfield and Van Aken, 2006):

i. Functional requirements (F);
ii. User requirements (U); and
iii. Design restrictions (D); and
iv. Attention points (A); and
v. Boundary conditions (B).

The following sections will go into depth on each of these aspects, uncovering the input details and outputs needed to develop a solution so that the desired aim set out at the beginning of the research in Chapter 1 and Chapter 3 can be met. This specification will provide both general and specific requirements to be used in the development and evaluation of the research product. The focus throughout is on what the research product must do and on providing details of how the research products' components will be developed. Guiding criteria will allow the structure to unite independent and impartial factors (Perimenis *et al.*, 2011). The following sections explain the structure of the requirements specification (see Table 5.1 to Table 5.5).

### 5.1.1 Functional requirements

In this section, the demands of the research product and the design of the functionality will be outlined. The functional requirements address functions that the research product must be able to perform in order to successfully meet its primary functionality demands (Waterman, 2008). Therefore, the selection process involves the determination of tools and techniques that satisfy conditions reflecting the specific user requirements.

*Table 5.1: Requirements specification for the research product - Functional requirements*

| Requirement ID | Requirements | Motivation |
|---|---|---|
| F1 | The research product should improve the social, environmental and economic stability of urban planning projects. | The main aim of the research study is to improve the triple bottom line of urban planning projects with the use of a research product, by utilising the triple bottom line scores to identify the probable change from the As-is state to the To-be state. |
| F2 | The research product should provide suggested tools or techniques to assist and enable improved sustainability. | By filtering a list of tools or techniques to support the user with urban planning projects, and giving suggestions with the implementation strategies for each tool or technique, the research product's output should assist the user to make decisions with regard to improving sustainable development. |
| F3 | The user data of eight criteria should be captured with several conditions for the research product to conduct evaluations. | The use of eight different criteria allows for all the combinations needed to filter an appropriate tool or technique for the user. Too many options would create unnecessary complexity and redundancies, while too few options would mean that not all the possible combinations of tools or techniques have been identified. |
| F4 | The research product should be able to evaluate the user's input using a ranking system. | The ranking system will always be able to deliver an output, because, if all the inputs do not match a tool or technique, then the highest ranked tool or technique will be chosen. This method will reduce output errors. |
| F5 | Users should be given related tools or techniques that support their objectives. | The research product should identify the user's as-is state and evaluate an appropriate tool or technique to achieve the user's to-be state. This is achievable by using the triple bottom line scores to assess the tools or techniques that would have the greatest impact on the specific area. |
| F6 | The research product should support continued and repeated usage. | The internal and external environment always changes. Therefore, urban planners should gain a new understanding of the importance of continuously improving the triple bottom line of urban systems. |
| F7 | The research product should be able to identify a set of candidates in terms of tools and techniques for consideration. | The important aspect is capturing the user input and handling the data correctly. The aim of the function is to manage the data correctly, and not to recommend an incorrect tool or technique for the user to consider for their project. |

### 5.1.2 User requirements

The user requirements refer to the set of requirements from the perspective of the user (Huff, Tranfield and Van Aken, 2006). Within this requirements specification, as in the previous section too all the tools and techniques are available to the user. Thereafter, the user's inputted conditions will be evaluated according to several criteria. The outcome will be a single tool or technique or multiple tools and techniques that should be used in conjunction to achieve the desired result.

The requirements in Table 5.2 are mostly conceptual. The user requirements do not specifically provide requirements in the design of the research product (Huff, Tranfield and Van Aken, 2006). However, the user requirements need to be verified to ensure that they are conceptually satisfied.

*Table 5.2: Requirements specification for the research product - User requirements*

| Requirement ID | Requirements | Motivation |
|---|---|---|
| U1 | The research product should be user friendly. | Presenting the user with a simple interface that is easy to understand should allow for optimised data collection. |
| U2 | The user should be able to apply their own discretion within the scope of their project | The research product is prescriptive in nature. Users should be allowed to repeatedly use the research product to tailor it to their specific situation, thus encouraging the ability to learn and improve. |
| U3 | The research product should be considered as a form of management support. | The urban planning team should be able to use the research product to assist with decision making. |
| U4 | The research product should assist users in choosing the appropriate candidates according to the evaluations. | Providing as much information as is available to the user will allow them to make their own deductions and judgement. This should also add another layer of visibility. By providing further explanation as to why and how that output was chosen, it can aid the user to support their final decision. |
| U5 | The research product should provide the references to enable users to find the supporting paper(s) that correspond(s) to the identified tool or technique suggested. | When the solution is provided to the user in the form of a tool or technique strategy, the next step is for the user to investigate the option(s). The research product should make the relevant reference(s) known to the user that is/are linked to the tool or technique, thereby offering guidance and justification. |

### 5.1.3 Design restrictions

This section looks at the requirements of the preferred solution, as well as the aim and omissions of the design (Huff, Tranfield and Van Aken, 2006).

*Table 5.3: Requirements specification for the research product - Design restrictions*

| Requirement ID | Restrictions | Motivation |
|---|---|---|
| D1 | The intention of the research product is not to develop new technology. | The research product should interlink the existing technologies based on the concepts of sustainable urban planning. |
| D2 | A high-level strategic approach for the research product should be the first method of the solution. | The research product will only provide the high-level strategic approach to achieving a balanced sustainable project. Therefore, the low-level operational approach will not be provided and must not be expected by users. |
| D3 | Any combination of user input needs to generate a result. | The users will have their own specific constraints within their project. It is for the research product to provide a strategy that resembles the input data. Therefore, if the conditions for the strategies do not match up precisely, then the output will be the highest rated tool or technique. |
| D4 | The research product is not a legal or legislative guide. | Legislation plays a major role in urban planning. Users should consult with specialists in this field when interpreting the results. |

### 5.1.4 Attention points

Attention points are relevant to the framework development; however, they are not requirements that have to be met but will be considered if they are not design obstacles (Huff, Tranfield and Van Aken, 2006).

*Table 5.4: Requirements specification for the research product - Attention points*

| Requirement ID | Attention points | Motivation |
|---|---|---|
| A1 | The approach should reflect early best practice within an evolving field of knowledge. | Academic research on urban planning sustainability within developing countries is still relatively underdeveloped. The design thus needs to draw from available expert content in the literature review. |
| A2 | Quantitative tools and techniques should be reviewed due to developing countries sometimes lack expertise and data availability. | The research product should take note of this lack of expertise and data availability, as this may be a deciding factor when developing a technological solution for sustainable urban planning. |
| A3 | The solution should not be more specific than is essential. | Minimal critical explanation is required in the design, as the main objective of the research product is only to improve and learn about balancing the triple bottom line of urban systems in developing countries. |

### 5.1.5 Boundary conditions

Boundary conditions must be met unconditionally for the research product design to succeed. The requirements have been compiled to ensure who is responsible and where the boundaries of application lie for the research product. These boundary conditions were adapted from the work of (Huff, Tranfield and Van Aken, 2006).

*Table 5.5: Requirements specification for the research product - Boundary conditions*

| Requirement ID | Boundary conditions | Motivation |
|---|---|---|
| B1 | The study has done as much as possible to reduce bias and remain ethical when judging the differences between different tools and techniques, in an attempt to increase sustainable urban planning in developing countries. | The SLR and AHP brought structure to the search for quantifying tools and techniques and their comparisons, in response to several conditions. Therefore, the user must use their own discretion and judgment to assess and accept the outcome from the research product. |
| B2 | Temporal and spatial scales within the assessment of deciding an appropriate tool or technique for a sustainable urban planning project come as close to accuracy in the real world as the SLR allows. | The accuracy of the temporal and spatial scales of the tools and techniques selected will be assessed by subject matter experts. This assessment will lead to a possible altering of parameters linked to tools and techniques to state their functions and outputs more openly and clearly. |
| B3 | This study is not held responsible for decisions made by the users. | The research product is only meant to support their decision-making process. |
| B4 | The research product only provides insight into possible strategies to achieving more balanced sustainable projects. | Therefore, the research product cannot provide data for evaluation toward the user's project management. |

## 5.2 Selection of decision-making method for research product

This section investigates different research products that could be useful to supporting urban planners with sustainable urban planning in developing countries. Three products are under investigation: (i) logic model framework, (ii) policy analysis framework and (iii) decision support framework. First a brief description with advantages and disadvantages for the respective frameworks (seen in Table 5.6).

*Table 5.6: Investigation of the advantages and disadvantages for the three possible research products.*

| Framework | Description | Advantages | Disadvantages |
|---|---|---|---|
| Logic model | "*A graphical/textual representation of how a program is intended to work and links outcomes with processes and the theoretical assumptions of the program*" (Hayes, Parchman and Howard, 2011, p. 576) | - Suitable for conceptualising initial business case.<br>- Flexibility when embedding performance measurements.<br>- Communication readily incorporated into training resources.<br>*Source: (Rodrigues et al., 2018)* | - Complexity grows and forces a step-by-step basis.<br>- Conflicts when integrating multiple logic views for different audiences.<br>- Requires deep understanding of organisational processes.<br>*Source: (Rodrigues et al., 2018)* |
| Policy analysis | *"Process of inquiry aimed at developing and critically assessing information to understand and improve public policies*" (Vogel and Henstra, 2015, p. 111) | - Allows for management to communicate leadership and holistic views.<br>- Defines the rules and procedures that apply to all stakeholders. | - Difficult to communicate to large organisations.<br>- Users might view policy as substitute for effective management.<br>- Policy development can restrict innovation and flexibility. |
| Decision support | Assisting the selection of an appropriate and applicable method or approach that will aid in a desirable outcome (Perimenis *et al.*, 2011). | - Utilise information to improve management decisions by incorporating key parameters within field of observation.<br>- Users receive specific solutions tailor-made to fit their situation.<br>*Source: (Kanatas et al., 2020)* | - Success of framework is based on experts and availability of technical resources.<br>- Risk associated with management adoption of new technology.<br>*Source: (Kanatas et al., 2020)* |

Given the requirements specification as set out in the previous sections and Table 5.6, it would be advisable to consider the creation of a decision support framework. Logic models have difficulty when adapting multiple different view for consideration, as seen in Table 5.6, which is the input needed to assess the 70 solution-specific tools and techniques. Furthermore, communicating an appropriate tool/technique for policy analysis might be difficult (see Table 5.6). This section is a generic assessment of research product frameworks. The investigation leads toward the drafting of a decision support framework. The requirements specification verifies this claim, (see Table 5.1 and Table 5.2) as the requirements need to evaluate multiple tools and techniques which are comparable via the MCDA study. The purpose of a decision support framework – which is similar to the purpose aimed to be developed in this research – is to assist in the selection of an appropriate and applicable method or approach that will aid in a desirable outcome (Perimenis *et al.*, 2011). The aim is to develop a decision support framework to assist urban planners when establishing a triple bottom line balance when managing urban system projects.

Complex and overly sophisticated decision support frameworks are known to mislead managers and complicate their outcome impression (Perimenis *et al.*, 2011). Therefore, the sensible approach is to develop a decision support framework that is understandable and offers high visibility and clear insight into the mechanisms. Following the requirements, restrictions, attention points and boundaries adapted from (Huff, Tranfield and Van Aken, 2006), a decision support framework will offer all the necessary functions to achieve the stated aim of the research study.

## 5.3 Conclusion: Chapter 5

This chapter focused on the requirements analysis which is the second phase of the systems engineering approach. The requirements specification stated the functional requirements, user requirements, design restrictions, attention points and boundary conditions. This led to drafting the research product as a decision support framework. The design of the decision support framework will be assessed and evaluated over the next three chapters.

Chapter 6 focuses on the functional analysis that explains how the requirements specification will be achieved to satisfy the aim of the research project. The purpose of the functional analysis is meeting the requirements set out in the requirements specification. The structured approach of systems engineering has provided a base on which to design a research product that can assist urban planners and researchers to convert cities in developing countries into sustainable systems that can more easily adapt to deal with a larger array of challenges.

# Chapter 6: Analysing the functionality of the decision support framework

This chapter sets out to accomplish objective RO3, (ii), as defined in Section 1.3, i.e., undertake a functional analysis of the requirements specification to design the research product. The aim of a functional analysis is to examine the requirements that were identified by the requirements specification and arranged into a coherent description of system functions (US Department of Defense Systems Management College, 2001). The purpose of such a requirements specification is to bridge the gap between the literature reviews and the solution development. In this chapter, therefore, the functional analysis will be used to investigate the requirements specification so that designing the decision support framework is a distinct and repeatable process (US Department of Defense Systems Management College, 2001).

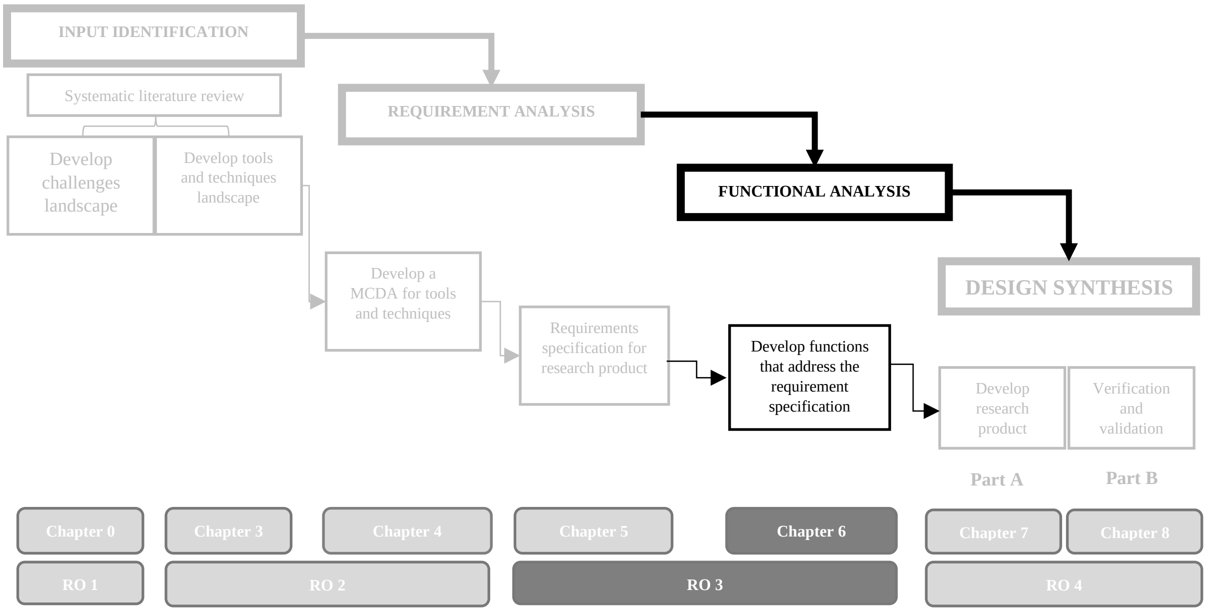



*Figure 6.1: Thesis schematic (Chapter 6)*

As stated, the systems engineering approach guides the study; the third step, which is discussed in this chapter, is the functional analysis (see Figure 6.1). The output from the functional analysis is intended to allocate them to specific tools and techniques that combine to form the high-level processes of the framework (US Department of Defense Systems Management College, 2001). Meaning, the solution needs the logical steps to be planned before implementing the final systems engineering phase. This chapter will cover the third research objective, namely, to undertake a functional analysis of the requirements specification to design the research product. The approach followed by the functional analysis is explained in the next section.

## 6.1 Functional analysis approach

This top-down process of translating system-level requirements (discussed in Chapter 4) into detailed functional and performance design criteria includes the following (US Department of Defense Systems Management College, 2001):

i. Defining the system in functional terms, then breaking down the top-level functions into subfunctions. That is, identifying at increasingly lower levels of detail what actions the system must carry out to achieve the high-level processes;
ii. Identifying and defining all internal and external functional interfaces; and
iii. Identifying functional groupings to minimize and control interfaces (functional partitioning).

"*Functional partitioning is the process of grouping functions that logically fit with the components likely to be used, and to minimize functional interfaces*" (US Department of Defense Systems Management College, 2001, p. 46). The three criteria outlined above will add to the structure of the functional analysis. These performance design criteria will be discussed in depth in Section 6.5. The first step is to define the functions that will develop the framework; as illustrated in Figure 6.2, these can be allocated to four additional elements: (i) inputs, (ii) controls, (iii) enablers and (iv) outputs.

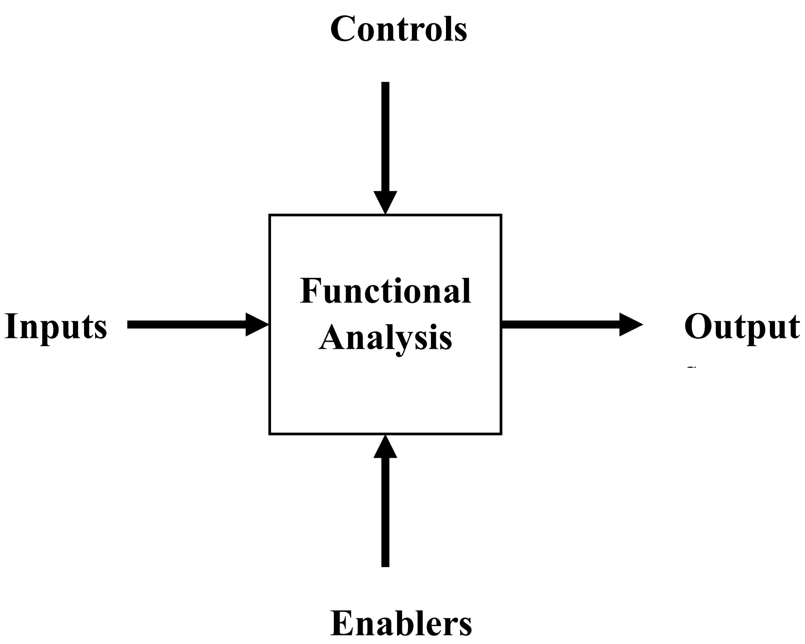



*Figure 6.2: Functional analysis activities. Source:* (US Department of Defense Systems Management College, 2001).

The sub-activities in each of the activities in Figure 6.2 are listed below:

i. Inputs: output of the requirement analysis;
ii. Controls: constraints;
iii. Enablers: functional flow block diagrams; and
iv. Outputs: design development

## 6.2 Functional analysis inputs

The third phase of the systems engineering approach has been illustrated in Figure 6.2 and will be elaborated on in the following sections. Starting with the inputs, known as the output of the requirement analysis. Chapter 4 gave a large amount of information converted from the AHP study, such as new definitions of each tool or technique in terms of city elements and SDGs, numerical data on how sustainable each tool or technique is, and a new scale to identify the impact of the tools and techniques regarding the triple bottom line.

By using the AHP scores for each tool and technique in Table 4.6, and the scale for the several intervals of the AHP scores for allocating points in Table 4.7, each tool and technique was allocated points, which were spread among the social, environmental and economic identifiers of the triple bottom line found in Table 4.8. This identification of the tools and techniques allows the functional analysis to build a decision support tool, as set out in the aim of the research project. Key tools and techniques that contribute strongly toward sustainable urban planning implementation are: (i) New urban agenda (AHP = 0.580), (ii) Green economic investment (AHP =0.512), (iii) Z-farming (AHP = 0.504 and (iv) Sustainable and green infrastructure (AHP = 0.501). These four tools and techniques were allocated 10 points to spread among the triple bottom line factors, according to how they function when implemented. The new urban agenda scored a 5, 3, 2 in social, environmental and economic factors. Green Economic Investment scored a 1, 4, 5 in social, environmental and economic factors. Z-farming scored a 2, 4, 4 in social, environmental and economic factors. Sustainable and Green Infrastructure scored a 2, 5, 3 in social, environmental and economic factors. These tools and techniques will ensure the greatest impact from the decision support tool output, due to their high AHP score, which allowed 10 points to be spread among the triple bottom line.

In Chapter 5, the requirements specification identified the functional requirements, user requirements, design restrictions, attention points and boundary conditions that were necessary to develop a research product that would achieve the aim set out for this study. A decision support framework was selected as the best option to accomplish the aim of the research product. This result was clear from evaluating all the requirements, restrictions, attention points and boundary conditions portrayed by (Huff, Tranfield and Van Aken, 2006). Table 5.1 to Table 5.5 in Chapter 5 listed the requirements that need to be achieved to successfully develop the decision support framework. In this chapter, the functional analysis will use these requirements to create a recipe to design such a decision support framework.

## 6.3 Functional analysis controls

The next activity within the functional analysis phase is to consider the control components, consisting of constraints and system concepts. This activity represents the scope of the framework development stage, ensuring that the development is realistic, manageable, and feasible.

Control constraints within the design are in place to ensure a simplified procedure and a controlled environment. Information processed within the decision support framework will only be gathered from the SLR, the tools and techniques landscape, the triple bottom line scores and the inputs provided by the user. Therefore, once the solution is fully developed and tested, the decision support framework would need to be updated before any new tools or techniques can contribute to the outcome of the process. In other words, the decision support framework can only output information that has contributed to this research study and will not gather information from outside the scope of the project.

## 6.4 Functional analysis enablers

This section develops the operating level of the functionality within the decision support framework. The functional flow block diagram (shown in Figure 6.2) provides a deeper look into the connections of the processes from input to output, and furthermore provides detail of the functionality of the requirements specification set out in Chapter 5, thus bridging the gap between what is needed and how it will be achieved. Table 6.1 lists the criteria and conditions that the user needs to input for the decision support framework to calculate an appropriate tool or technique for their project.

*Table 6.1: User data input criteria and conditions. Source: Author*

| Criteria | Conditions |
|---|---|
| Type of area | Element of the city system |
| Size of area | Block/Suburb/City wide |
| Data intensity | Qualitative/Quantitative |
| Participation necessity | Public/Private/Governmental cooperation |
| As-is state | Environmental/Social/Economic |
| To-be state | Environmental/Social/Economic |
| Cost/budget | Minimal/Infinite |
| Probability of success | Implementation difficulty |

The following list provides a brief description of the criteria provided in Table 6.1. Each criterion in this list will also provide the source/reference of where the information was used/derived. Furthermore, providing an example of how the decision support framework will add up the points for the specific criteria. The points for the framework will be elaborated in the example in Table 7.1:

i. Type of area (elements of the city system (Dempsey *et al.*, 2010) found in Table 2.3)
   a. Inputting the residential element will filter those tools and techniques that were associated with that element and that scored additional points.
ii. Size of area
   a. Inputting a block-sized[2] area will filter the tools and techniques that contribute to more specific projects.
iii. Data intensity
   a. Derived from the qualitative/quantitative category derived from Section 3.4, which was the 4$^{th}$ step of the categorisation hierarchy. (Note that a lack of data input will generate qualitative tools or techniques by the decision support framework).
iv. Participation necessity
   a. An example of a public participation technique is recycling (Specht *et al.*, 2014). This technique requires assistance from the public to contribute to a project (Davoudi and

[2] An established minimum standards for new developments, often measured in terms of block size (Stangl, 2015).

Sturzaker, 2017). These types of tools and techniques will be given a certain number of points by the decision support framework if they meet the criteria.

b. An example of private participation would be for a LEED rating technique that was implemented by a private company for evaluation (Dur, Yigitcanlar and Bunker, 2014; Mohareb, Derrible and Peiravian, 2016). These types of tools or techniques will be granted additional points by the decision support framework.

c. Large system-changing tools or techniques that require governmental approval to proceed will be filtered and points awarded accordingly (see case study examples, Table 8.11, Table 8.14 and Table 8.17).

v. As-is State (Source: Author)

a. This criterion identifies the current situation on the project that the urban planner is dealing with.

b. An example for the framework would be; providing an environmental state would filter out all the tools and techniques that focus on the environment. This way, the tool or technique chosen will more likely improve the balance of the other states (social/economic).

vi. To-be State (Source: Author)

a. This criterion identifies the future situation of the project where the urban planner would like to achieve sustainable goals.

b. An example for the framework would be; providing a social state will filter all the tools and techniques that focus on social equality. This way, the tool or technique chosen will more likely improve the balance of that state.

vii. Cost/budget (Source: Author)

a. An example situation provided by the framework would be if, a small budget were selected, this will only provide a small set of tools and techniques to be selected for an optimal strategy, whereas, a larger budget will give rise to offers of more tools and techniques.

viii. Probability of success (Source: Author)

a. This criterion is linked to different conditions. For instance, larger projects will be more complicated, and socially focused projects will need more time for people to become accustomed to change. Therefore, tools that fit this filter will be portrayed in the final output of the decision support tool to provide a realistic outlook for the user.

Note that there are eight criteria that have several conditions from which users can choose. This level of diversity allows the decision support framework to deliver a wide range of outputs, being the 70 solution-specific tools or techniques covered in the tools and techniques landscape in Table 3.2. Furthermore, accompanied by the triple bottom line scores of Table 4.8, the conditions of the as-is and to-be states will be calculated in the decision support framework (see requirement F5 in Table 5.1). To elaborate how the functions will be carried out to achieve the requirements set out in the requirements specification (see Table 5.1 - Table 5.5), functional flow block diagrams will be presented in the next section.

### 6.4.1 Functional flow block diagrams

Functional flow block diagrams define task sequences and relationships (US Department of Defense Systems Management College, 2001). With the sequence of events structure, the functions of each process will flow toward generating the strategy best suited to finding a sustainable balance for the user. Figure 6.3 illustrates the structure and order of the relevant processes that the decision support framework will do. Furthermore, reveal when and which data stores (tools and techniques landscape, and triple bottom line scores) will be accessed during the strategy generation process.

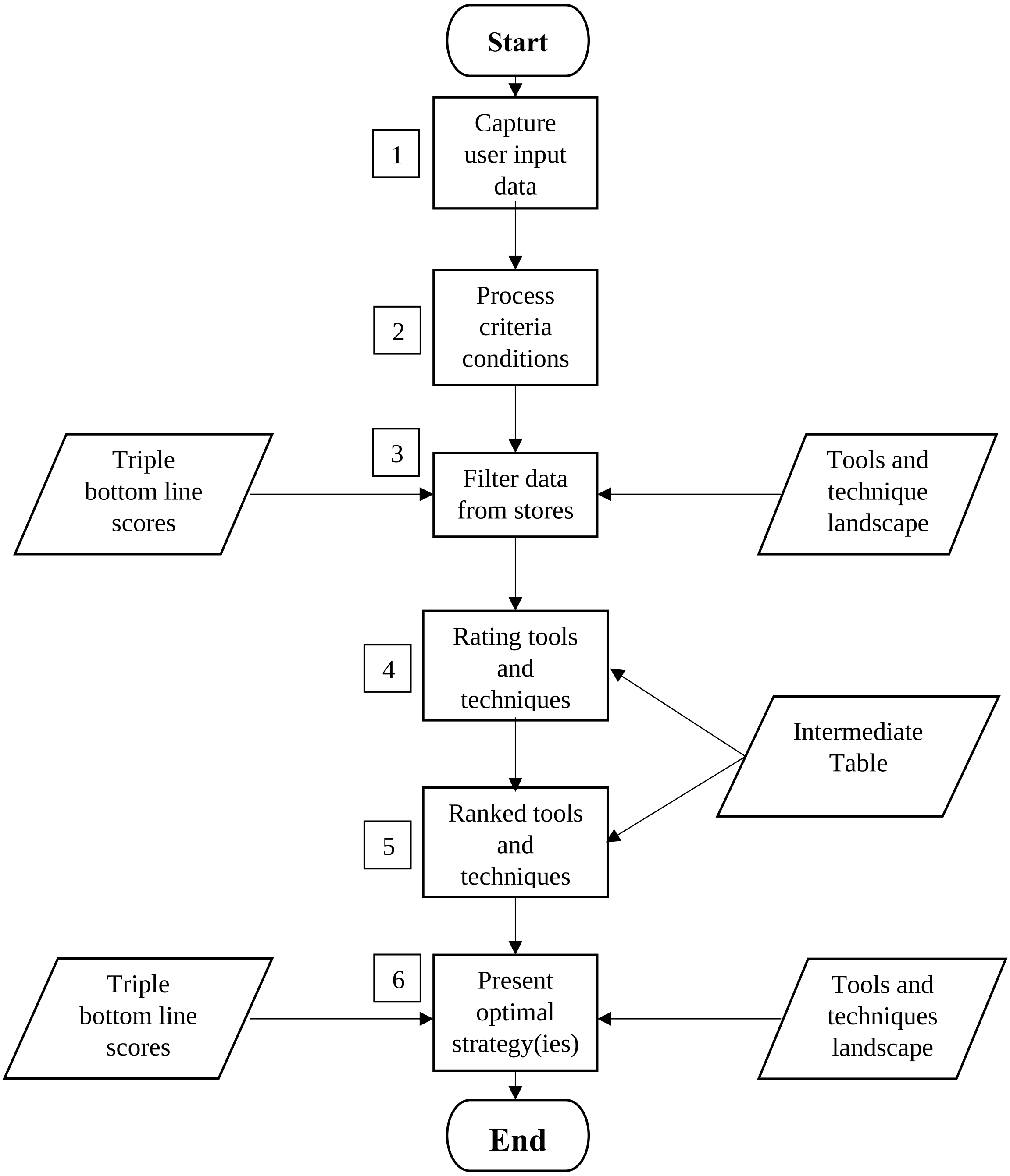



*Figure 6.3: Functional flow block diagram of strategy generation*

With the sequence of the tasks established in Figure 6.3, the functions of each process can be developed along with each subfunction:

i. Capture input data;
ii. Process criteria conditions;
    a. Evaluate the conditions from each criterion.
iii. Filter data from stores;
    a. Using filters in the tools and techniques landscape and the triple bottom line scores to identify the relevant candidates.
iv. Rating tools and techniques;
    a. Applying points to the tools or techniques that are associated with the conditions entered by the user.
v. Ranked tools and techniques; and
    a. Final scores will be ranked according to an unbiased assessment.
vi. Present optimal strategy(ies)
    a. Presenting all the information regarding the optimal tool(s)/technique(s) to satisfy the user's inputs.

#### *6.4.1.1 Functional flow block diagram for the intermediate table*

Following tasks 2 & 3 from Figure 6.3, the process and filter steps are illustrated in Figure 6.4. Section 5.1 developed the requirements specification tables (see Table 5.1 to Table 5.5). These tables explained the motivation for each requirement that was necessary to develop the decision support framework. The functional flow block diagrams elaborate on the processes that will achieve the stated requirements in Table 5.1 to Table 5.5. However, not all the requirements, restrictions, attention points or boundaries will be covered by the functional flow block diagrams.

Requirements F3, F7, U4 and D3 (see Table 5.1 to Table 5.3) are covered with the following flow block diagram. Note that (n) is the number of input criteria, and (m) is the number of rows/tools and techniques. There are 8 criteria conditions the user must input before submitting the user data to the decision support framework (see Table 6.1). Examples of the intermediate table will be given in Appendix C. Figure 6.4 begins by examining the first loop for the first criteria that the user inputted. If there was a match with the first tool or technique, the tool or technique in the intermediate table receives a point for the match, then loops to the next tool or technique to check that match. Otherwise, if there was no match, the loop goes straight to the next tool or technique without adding a point in the intermediate table. While the evaluations of the criteria are computed for the 70 different tools or techniques, the intermediate table is collecting points whenever there is a match. When the first criterion has been completed for the 70 tools or techniques, the loop starts again on the next criterion. The loop is continually adding points to the intermediate table, though only for the matches. Once all 8 criteria have been evaluated in this way, the filtering process is completed and a compiled intermediate table is produced.

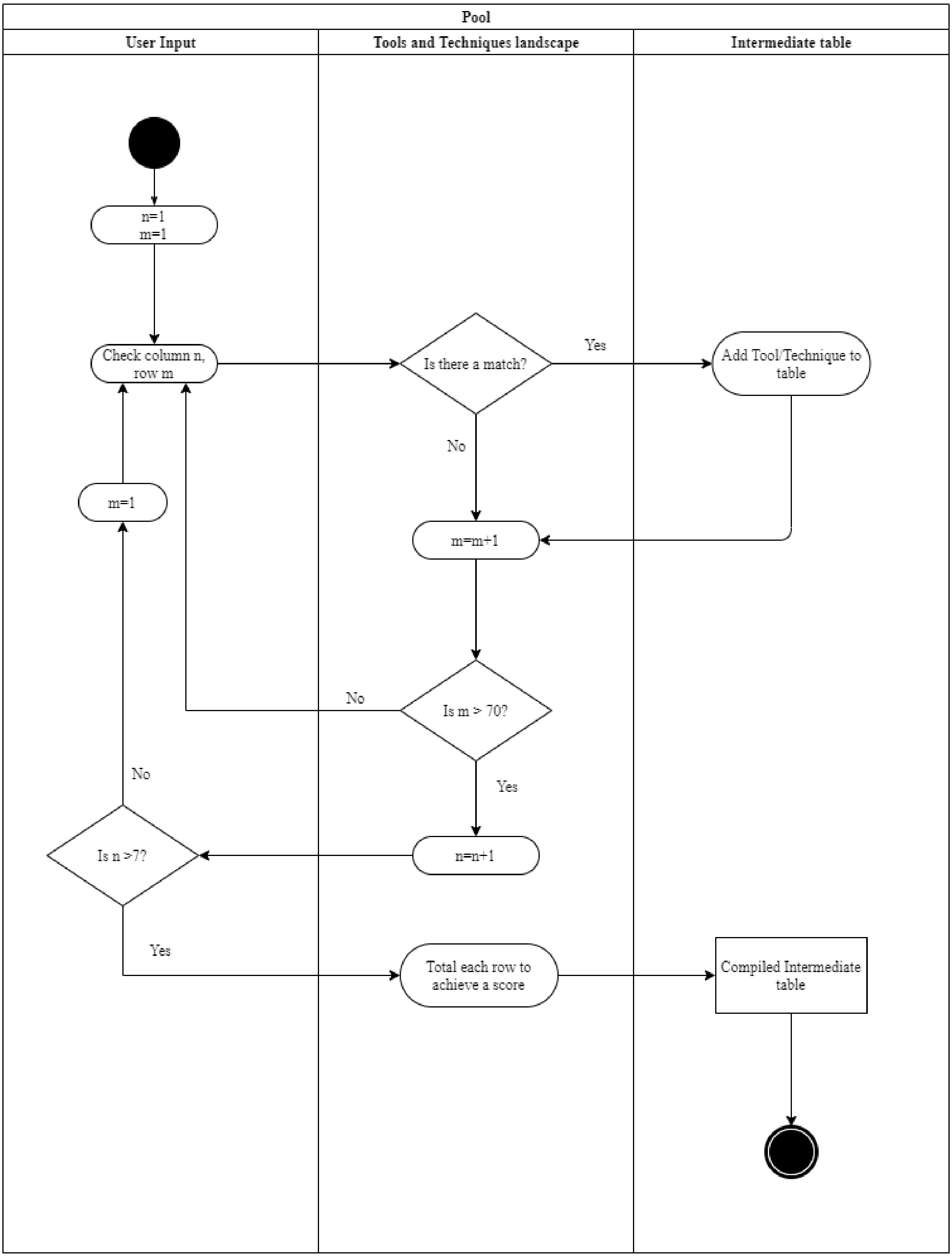



*Figure 6.4: Functional flow block diagram of process and filter steps*

Every correlating input that corresponds to the tool or technique will have a point awarded. Therefore, the tool or technique with the most points represents an appropriate strategy for the particular user's input parameters. This approach will also ensure that the final user output is transparent, because it displays the corresponding inputs that matched and that did not match.

#### *6.4.1.2 Functional flow block diagram for calculation of as-is and to-be states*

The triple bottom line scores from Table 4.8 in Chapter 4 were specifically developed for this one purpose (i.e. to numerically differentiate between each tool and technique), while the MCDA generated numerical value to identify the differences according to a scale (shown in Table 4.7). This scale was then used to allocate points among social, environmental and economic states that correspond to the as-is and to-be states of the user inputs. Following tasks 3 & 4 from Figure 6.3, the filter and rating steps are illustrated in Figure 6.5. Similarly, as in the previous functional flow block diagram, the columns will first identify whether there is a match. Within the as-is column, if there is a match, the triple bottom line points associated with that tool or technique will be subtracted. Therefore, tools and techniques will not be awarding points for users that do not require assistance within that tool or technique's state (social, environmental or economic state). This example is discussed in Appendix C. When all the 70 tools or techniques have been evaluated within the as-is state column, it continues to the next column, the to-be state. When the tools or techniques have a match with the triple bottom line states, their points are added to the intermediate table. If the user intends for their project to contribute to specific triple bottom line states, the tools and techniques corresponding to those states will have their points added to the intermediate table, thus fulfilling requirements F3, F4, F5, U4 and D3, as listed in Table 5.1, Table 5.2 and Table 5.3.

#### *6.4.1.3 Functional flow block diagram for compiled user output*

The intermediate table must be initially displayed to users, so that they can identify the process flow of an appropriate tool or technique that met each criteria and condition. Following tasks 5 & 6 from Figure 6.3, the ranking and presenting steps are illustrated in Figure 6.6. The strategy generation checks each column in the intermediate table, before providing a reason or purpose for each criterion. It thus provides direction and cautions in respect of the tool and technique that was identified as appropriate for the user's sustainable urban planning project. It further provides the reference in the literature to enable the user to find the supporting paper that corresponds to the identified tool or technique. This therefore fulfils requirements F2, U3, U5 and D2, as shown in Table 5.1, Table 5.2 and Table 5.3.

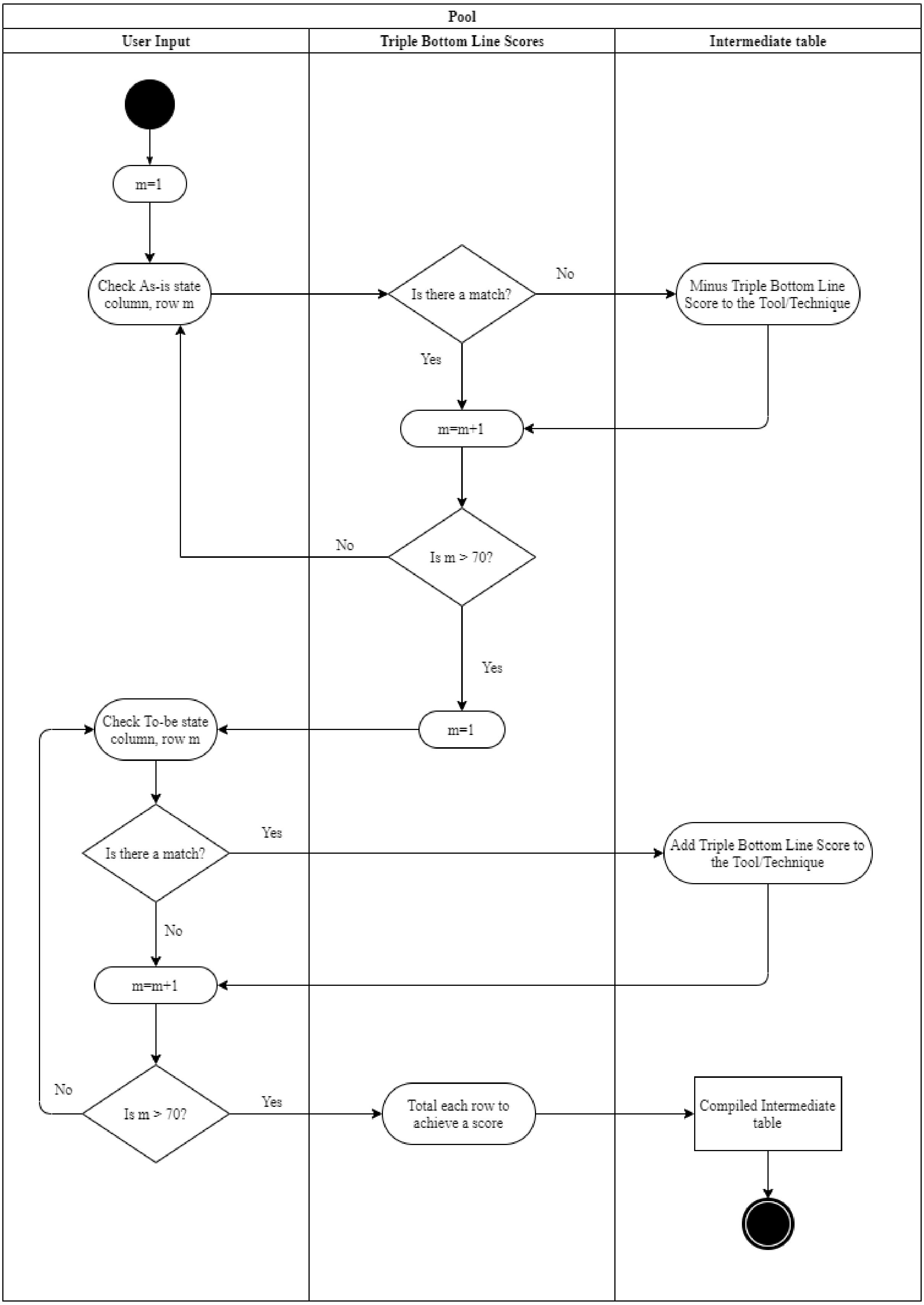



*Figure 6.5: Functional flow block diagram of filter and rating steps*

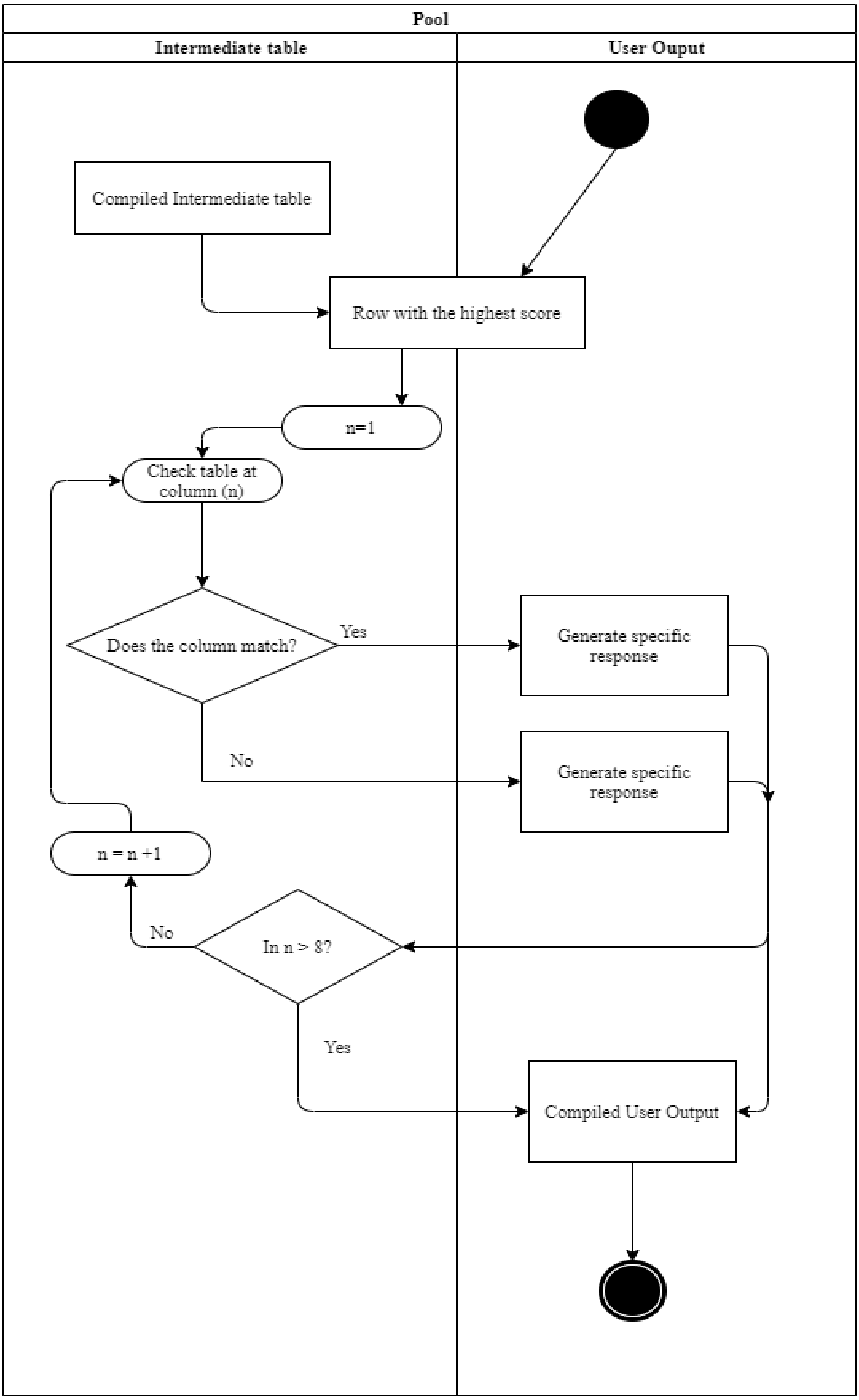



*Figure 6.6: Functional flow block diagram of ranking and presenting steps*

## 6.5 Functional analysis outputs

The requirements specification developed in Chapter 5 provided much to account for in the functionality analysis. This section captures the outcome of the development toward the decision support framework, which was initiated by the requirements specification. The three performance design criteria of the third phase of the systems engineering approach provided in Section 6.1 will be addressed in this section. To reiterate, the criteria were: firstly, defining the system in functional terms; secondly, identifying and defining all internal and external functional interfaces; and thirdly, identifying functional groupings.

### 6.5.1 Defining the system in functional terms

By breaking down the top-level functions into subfunctions, it identifies sequential lower levels of actions that the system must accomplish. These performance design criteria bridge the gap from phase 2 to phase 3 of the systems engineering approach. The requirements specification developed in Chapter 5 elaborated on the five requirement types (Huff, Tranfield and Van Aken, 2006): (i) functional requirements, (ii) user requirements, (iii) design restrictions, (iv) attention points and (v) boundary conditions, which were all discussed in Section 5.1.

The purpose of a decision support frameworks is to assist in the selection of an appropriate and advanced method or approach that will aid in achieving a desirable outcome (Perimenis *et al.*, 2011). Therefore, the selection process needed certain function to capture the user's input, in order to then output the appropriate approach. In theory, this is a straightforward process, but the functioning, low-level processes needed a certain structure and logic. Figure 6.3 illustrates the step-by-step process that was followed to capture the data, evaluate the information, and calculate the necessary scores in order for the system to output the optimal strategy for the user to implement in their sustainable project. The user requirements covered a range of options to cover the needs of the user, while restricting the complexity of the framework. The next requirement type also connects to the user requirements. Design restrictions placed some constraints on the system too, namely: how much input do we need from the user to provide a confident analysis toward an optimal strategy, and how can we reduce the number of inputs to decrease complexity and mundane rudimentary inputs that will not significantly affect the output? The carefully selected user requirements were checked alongside the design restrictions. The attention points to cover in the functionality revolved around transparency, by delivering to the user a decision support framework that offers what the user needs, without overloading them with excessive amounts of data. Furthermore, it is important to build in the functions that allow for a simple transparent experience, where the user is notified of how their inputs contribute toward the output. Lastly, the system must maintain conditions to set the boundaries for the decision support framework. Temporal and spatial scales within assessment of deciding an appropriate tool or technique for a sustainable urban planning project come as close to accuracy in the real world as provided in the SLR. The accuracy of this system will furthermore be assessed by SMEs. Regarding functional requirements, it is hard to achieve a sense of real-world connectedness within the scope of this study. Its aim is to assist sustainable urban planners to increase their triple bottom line, i.e., by increasing social equality, environmental prosperity and economic stability. Therefore, the function in the decision support framework must convey enough information to deliver the desired results to the user in the context of developing a balanced triple bottom line.

### 6.5.2 Identifying and defining all internal and external functional interfaces

Identifying and defining all internal and external functional interfaces reveals the factors that affect the system. This will outline the scope of the system within a definitive set boundary. The external interface for this system contributes to the framework. The external functional interface is the user input, as covered in the user requirement section. This must still be assessed and evaluated by SMEs to ensure that the system delivers desirable results. Therefore, this interface needs to present a simple, easy to use, hassle-free input system. The design and presentation of the interfaces will be covered in the following chapter.

Figure 4.2 introduced the internal interfaces that the decision support framework will use, namely, the challenges landscape and tools and techniques landscape, followed by the AHP assessment. All contribute toward the requirement analysis. At this stage, the internal functional interfaces will not be apparent to the user. This will mean that there is less clutter and thus a smoother experience for the user. The internal interfaces contain all the necessary information that contribute to analysing the user inputs and delivering the optimal strategy. This covers another design restriction. The only analysis done with regard to the user input will be using the internal functional interfaces. Therefore, there will be no assistance from outside material, such as the internet, but only what is covered and presented in this research study.

## 6.6 Conclusion: Chapter 6

The objective of this chapter was to undertake a functional analysis of the requirements specification. This functional analysis comprised the third phase of the systems engineering approach, and it is important in joining the requirements with the design of the solution. By connecting the requirements specification with the lower level functions that drive the decision support framework, it entailed a thorough investigation to ensure that all functions are accounted for. The functional analysis also justifies that the requirements are reasonable and achievable for a system to compute. Combining the requirements specification with the functional analysis produces a blueprint for the final phase of the systems engineering approach, which will be presented in Chapters 7 and 8 below. The design synthesis phase will consist of two parts, first developing the decision support framework, and then verification and validation of this with SMEs.

Chapter 7 focuses on the development of the sustainable urban planning assistant decision support framework (SUPA DSF). Continuing onto the fourth phase of the systems engineering approach, namely, design synthesis.

# Chapter 7: Development of the sustainable urban planning assistant decision support framework

This chapter presents the development of the research product (i.e. the Sustainable Urban Planning Assistant Decision Support Framework [SUPA DSF]), which will address the aim of the study, beginning with the purpose of development and then describing the overview for the framework, followed by the conceptualisation of the SUPA DSF. With regard to the final phase of the systems engineering approach, Part A of the Design Synthesis is illustrated in Figure 7.1.

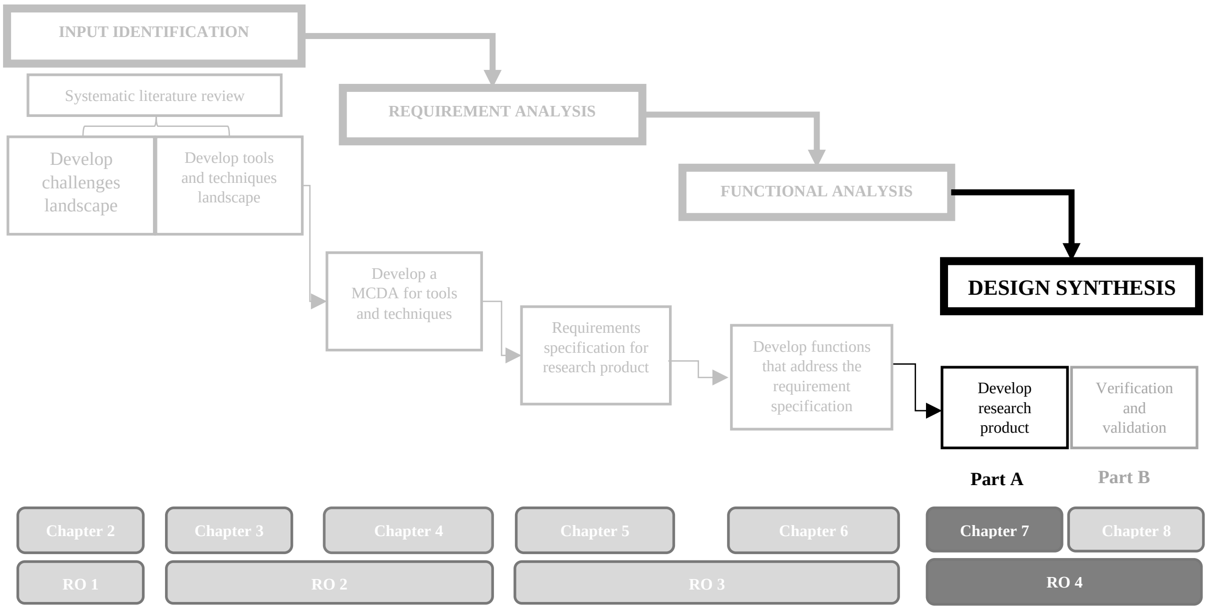



*Figure 7.1: Thesis schematic (Chapter 7)*

## 7.1 Purpose of the SUPA DSF

The intended purpose of the final phase of the systems engineering approach is to synthesise the operationality of the functional analysis, which provides the processes and functions that address the aim of the research. It thus evaluates tools and techniques specific to sustainable urban planning solutions that assist users to implement sustainable practices in their projects. Moreover, a triple bottom line is used to achieve a balance between the social, environmental, and economic states of an urban planning project. Furthermore, when considering an implementation strategy for the user, as well as the criteria and conditions of the project specific to the user, the DSF only gives an overview of the optimal strategy and not the operational or financial feasibility.

## 7.2 Development of the DSF

The fourth and final phase of the systems engineering approach is geared towards the development of ideas based on functional descriptions from the functional analysis (US Department of Defense Systems Management College, 2001). Design synthesis is an inventive activity of emerging a conceptual framework sufficient to executing functions within the scope and constraints of the project (US Department of Defense Systems Management College, 2001). The objective of a design synthesis is to associate and streamline the relevant components of the SUPA DSF that have been designed to achieve the aim and objectives of the project as stated in Section 1.3.

In the case of this research, the research product (i.e. the SUPA DSF) is the output for the design synthesis. The foundation forms documentation such as work breakdown structures (WBS). The SUPA DSF emerged from 3 WBS: (i) the intermediate table, (ii) the calculation of as-is and to-be states, and (iii) the compiled user output. The WBS are shown for each part of the DSF in Figure 6.4 - Figure 6.6 of Chapter 6. The development process op the SUPA includes four phases, i.e. (i) correlation of SUPA DSF the with functional analysis, (ii) a process WBS for the conceptualisation of the SUPA DSF, (iii) concepts (i.e. dimensions of the SUPA DSF) theoretically verified through a process of verification and, (iv) all supporting information regarding input and output for the SUPA DSF documented in Appendix C. Phases (i) and (ii) of the SUPA development are covered in Chapter 7 which is Part A of the Design Synthesis (i.e. develop research product) as shown in the thesis schematic in Figure 7.1. Part B of the design synthesis (i.e. verification and validation processes) will cover (iii) and (iv) of the conceptualisation of the development process of the SUPA DSF and are discussed in Section 8.3 – 8.8.

### 7.2.1 SUPA DSF overview

The SUPA DSF contains 4 dimensions, i.e., Dimension 1 – User input, Dimension 2 – Sustainable urban planning strategy index, Dimension 3 – Triple bottom line balancing, and Dimension 4 – User output. These dimensions combined form the decision support framework. The input section is found in Dimension 1, requiring user interaction in the form of input data. Dimensions 2 and 3 are the background logic level, and the user output is found in Dimension 4.

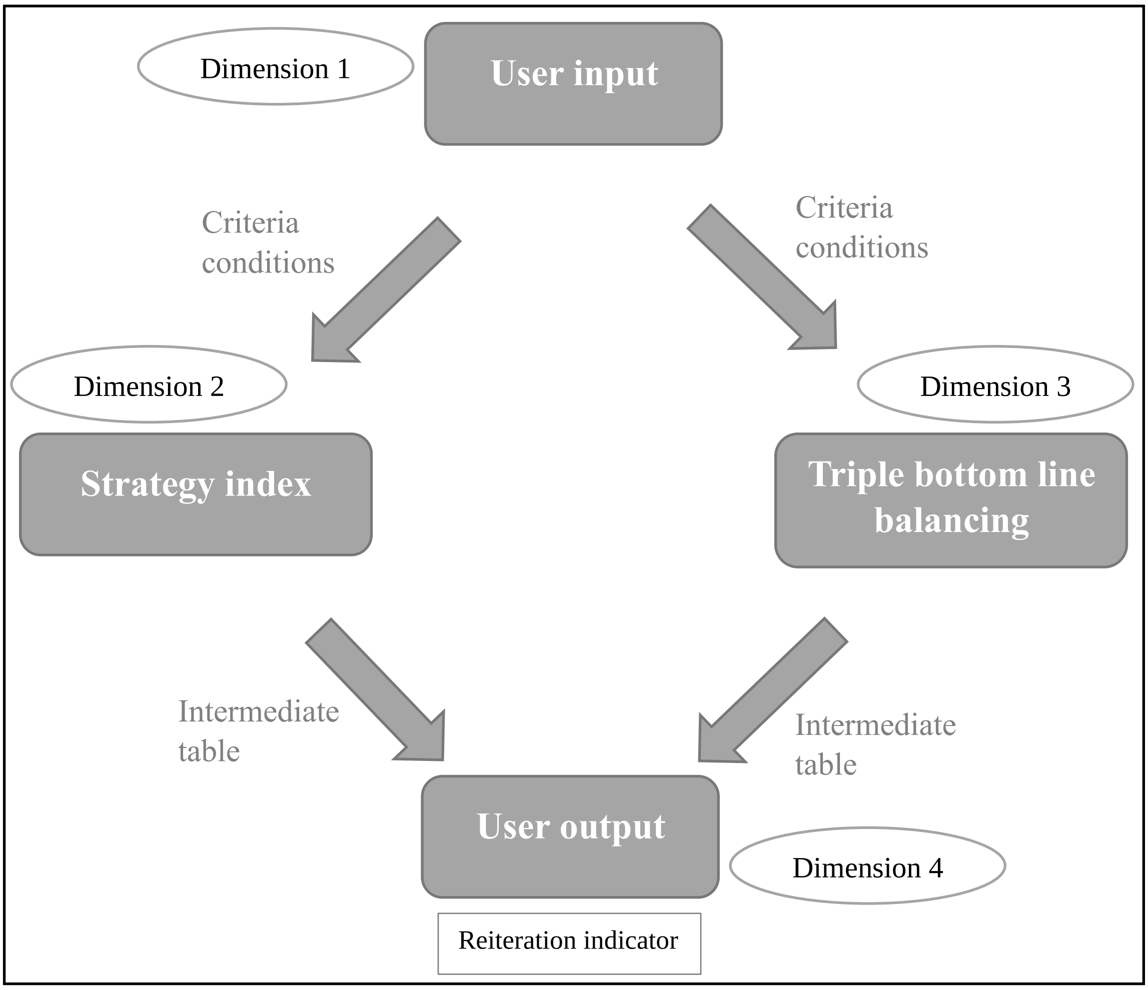



*Figure 7.2: SUPA DSF diagrammatic overview*

Dimension 1 is the User input, whose aim it is to capture and process the required user input data. This consists of 8 criteria (i.e. Type of area, Size of area, Participation necessity, As-is state, To-be state, Data intensity, Probability of success, Cost/budget) with corresponding conditions that contribute to the required user input. These 8 criteria were first established in Table 6.1 of the previous chapter. Section 7.3.1 elaborates on these criteria, with some examples. The user is required to complete all eight inputs to optimise the decision support framework calculations (the projects needs are considered in the user input data). Dimension 1 is further discussed in Section 7.3.1.

Dimension 2 is the Sustainable urban planning – Strategy index, which refers, in particular, to the 70 solution-specific tools/techniques that will provide the strategy for urban planners according to the user input. This dimension serves as the background logic that will be searched using the 6 out of 8 criteria inputted in Dimension 1 (shown in Figure 7.3). The data are filtered to match an appropriate tool and technique to satisfy the user's sustainable urban planning project needs (the projects needs are considered in the user input data). This dimension will be further discussed in Section 7.3.2.

Dimension 3 contains the triple bottom line balancing developed from the MCDA in Section 4.5. This dimension targets the as-is state and to-be state of the criteria from the user input in Dimension 1. Using the criteria provided, the triple bottom line scores linked to each tool or technique are assessed to identify the highest contribution toward the social/environment/economic state that the user requires for their specific project. This dimension will be further discussed in Section 7.3.3.

Dimension 4 is the implementation strategy, which provides the user with a customised strategy to assist in the realisation of the urban planning project by identifying an appropriate tool/technique, given the context they had inputted. The operational, financial, and technical feasibility of the strategies, however, fall outside of the research scope.

The reiteration indicator is a recommended optional timeline to perform the SUPA DSF again so that the urban planner includes continuous improvement within the project. The premise is to use new input conditions that relate to the updated project by the urban planner. Therefore, for example, the previous to-be state of the current project should be the new as-is state for the reiteration of the SUPA DSF. The new tool or technique outputted by the SUPA DSF should allow the user new perspective and more options for the ongoing sustainable project. Each of the four dimensions of the SUPA DSF is discussed in more detail in the following sections.

## 7.3 Detailed discussion of the SUPA DSF

An important part of design synthesis is the use of modular design, which entails grouping together components that perform independent tasks, or grouping together related facilities that increase the probability of finding more effective solutions (US Department of Defense Systems Management College, 2001). The functional analysis was paramount in the design of the SUPA DSF, as it involved using all the enablers from the functional analysis, namely the functional flow block diagrams, to synthesise the structure and assembly of the framework. Each of the four dimensions mentioned in the previous section will be discussed in more detail below, while furthermore connecting the functional flow block diagram of Figure 6.3 to each dimension.

### 7.3.1 Dimension 1: User input

The intent of this dimension is to determine the project's relevant information regarding the implementation of the SUPA DSF's best fit for that specific project. This dimension is situated in the user interface and requires the user to address eight different questions. All eight questions are required to assist the SUPA DSF in identifying an appropriate tool/technique to develop the project in order to satisfy the user's requirements. Figure 7.3 shows the data that is extracted from the user input and used in the strategy index and triple bottom line scores table. The data comprises criteria such as type of area, size of area, data intensity, participation necessity, probability of success, cost/budget for the strategy index, and these are combined with the as-is and to-be states in the triple bottom line scores table. Once the information for the eight questions are captured, the user input is transferred to Dimension 2 and Dimension 3. The following overview for the eight questions are briefly defined in the following subsections.

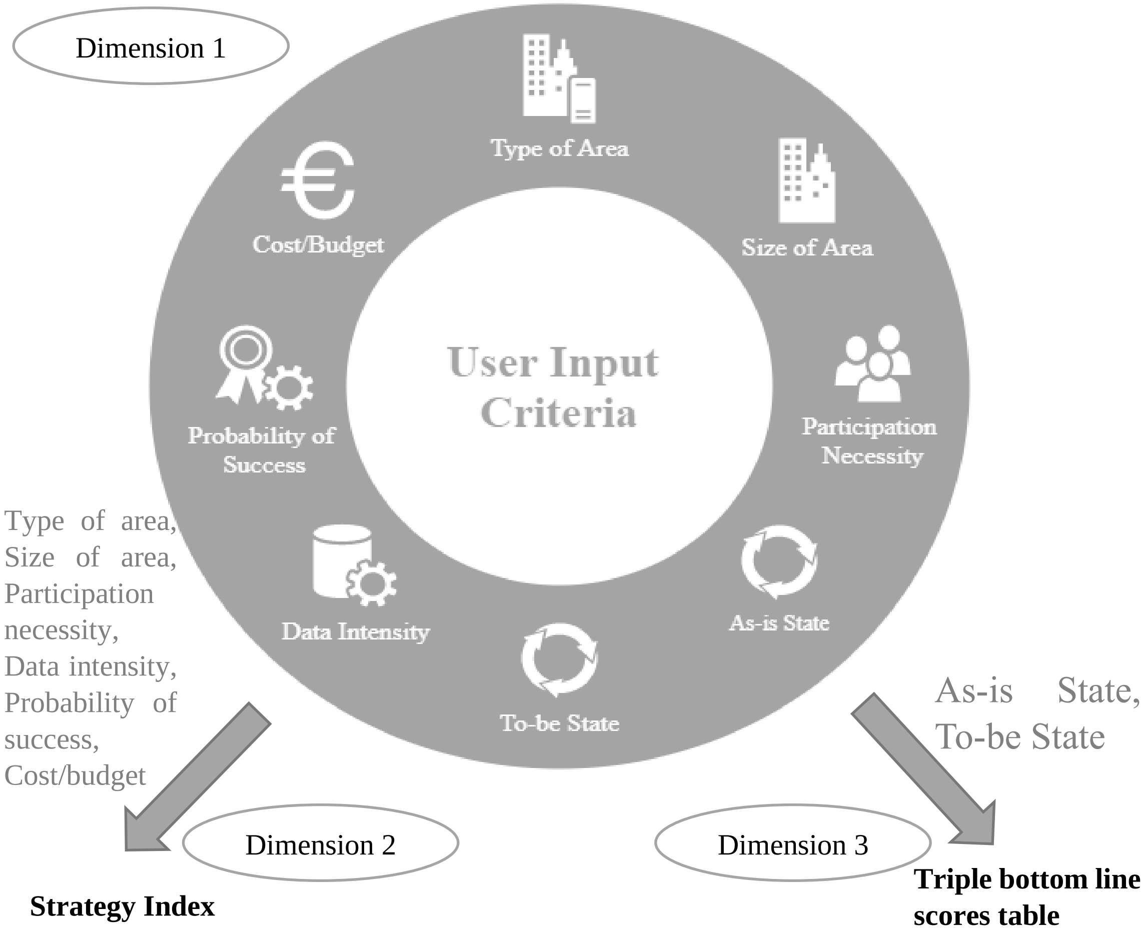



*Figure 7.3: 8 User input criteria (Source: Author)*

#### *7.3.1.1 Criterion: Type of area*

Type of area is the criterion concerned with the elements of the city system. As set out in Section 2.5.1, the elements of the city system are the ten different aspects that make up a city (Dempsey *et al.*, 2010). The sustainable urban planning challenges from the SLR and the tools and techniques were defined according to the city system elements so as to facilitate an unbiased comparison between them.

#### *7.3.1.2 Criterion: Size of area*

Size of area is the criterion that defines the space, which covers the tool/techniques area of transformation. The user may only be concerned with a small geographical area, such as a single building, or it may be a larger area, such as the CBD of a city. This criterion thus considers the size of the area and thus the size of the potential impact of the user’s project.

#### *7.3.1.3 Criterion: Data intensity*

Data intensity is concerned with the data availability that surrounds the project. In developing countries, this is a common major concern. The lack of data availability restricts competitive improvements in the domain of sustainability for developing countries. That is why this criterion is included in the decision support framework.

#### *7.3.1.4 Criterion: Participation necessity*

This concerns the level of cooperation needed for successful implementation of the user's sustainability project. In the case of public cooperation, the public would need to assist over a period of time and by participating in a mental change of action. Therefore, their assistance is purely cooperation based and used as a source of qualitative data for further input in relation to the tools or techniques. The public would not, however, be involved with the planning of construction. Private cooperation means that, in order to implement the tool/technique, only the resources and operating capacity of the company that is implementing the project are required. Governmental participation requires a systemic change that alters people's behaviour at the highest level of co-operation, or that enforces such a change in behaviour.

#### *7.3.1.5 Criterion: As-is State*

As-is state refers to the current domain along the triple bottom line where the user has approached the project. If the situation is currently focused on the economic benefits, then the input will be economic.

#### *7.3.1.6 Criterion: To-be State*

To-be state refers to the end goal the user wants to achieve. If the CBD of a city is currently focused on economic gains and would like to increase its environmental stability, then the user will input an environmental to-be state.

#### *7.3.1.7 Criterion: Cost/Budget*

The cost/budget criterion is up to the discretion of the user. If the user has a set budget that must be applied toward the project, then this input can be included. Then a specific category will determine a group of tools/techniques that best fit that condition. This criterion may be subject to criticism, as information regarding the monetary factors relating to the tools and techniques was not disclosed in the SLR. Therefore, the cost/budget/financial aspects relating to the tools/techniques weren't properly studied, thus this part of the framework is not fully worked out, and thus could be a limitation that reduces the applicability of the options suggested by the framework.

#### *7.3.1.8 Criterion: Probability of success*

As probability of success is one of the most important issues in highly competitive markets, companies need to quantify the impact of reducing implementation time, which can also be used to justify investments in new tools or techniques (Perimenis *et al.*, 2011). This should not be confused with implementation difficulty, which is indirectly proportional to the probability of success. Therefore, the user dictates the desired implementation difficulty, and then the SUPA DSF outputs the probability of success.

### 7.3.2 Dimension 2: SUPA – Strategy index

The second dimension of the SUPA DSF is the strategy index, which was developed in Chapter 3. This index provides an overview of the different tools/techniques that may assist with the decision support framework. For reference, the strategy index lists the 70 solution-specific tools/techniques that were determined through content analysis of the 41 papers in the SLR. Using a categorisation method to differentiate between the tools/techniques found in Figure 3.2, 70 tools and techniques that can assist sustainable urban planning projects were identified. The SUPA DSF – Strategy Index is illustrated in

Figure 7.5, which divides it into their respective units of analysis (Sustainable urban planning, Sustainable development, Smart city, Eco-city and Adaptation planning). The list of the tools and techniques found in the content analysis can be found in Appendix C.

Dimension 2 is connected to Dimension 1, in which the user input is captured and compared to the tools and techniques within the strategy index to identify the appropriate tool/technique to satisfy the particular requirements of the user. The functional flow block diagram that illustrates these functions can be found in and Figure 6.4 and Figure 6.5 of the previous chapter. Figure 7.4 shows the first part of the process flow diagram of Figure 6.3; it shows how the background logic from the strategy index is filtered and added to the intermediate table. When there is a match with a tool/technique from the strategy index, the intermediate table adds 1 point in the corresponding column. If the column does not match the tool/technique with the user input, the intermediate table adds 0 points in the corresponding column.

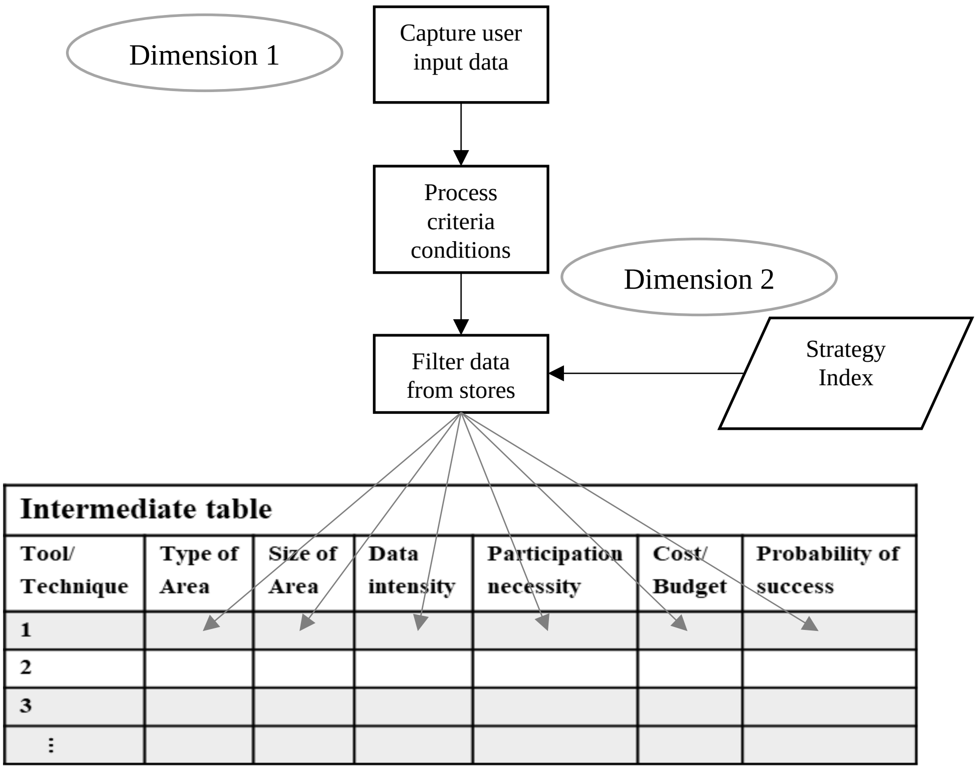



*Figure 7.4: Process flow breakdown for Dimension 1 and 2 (Source: Author)*

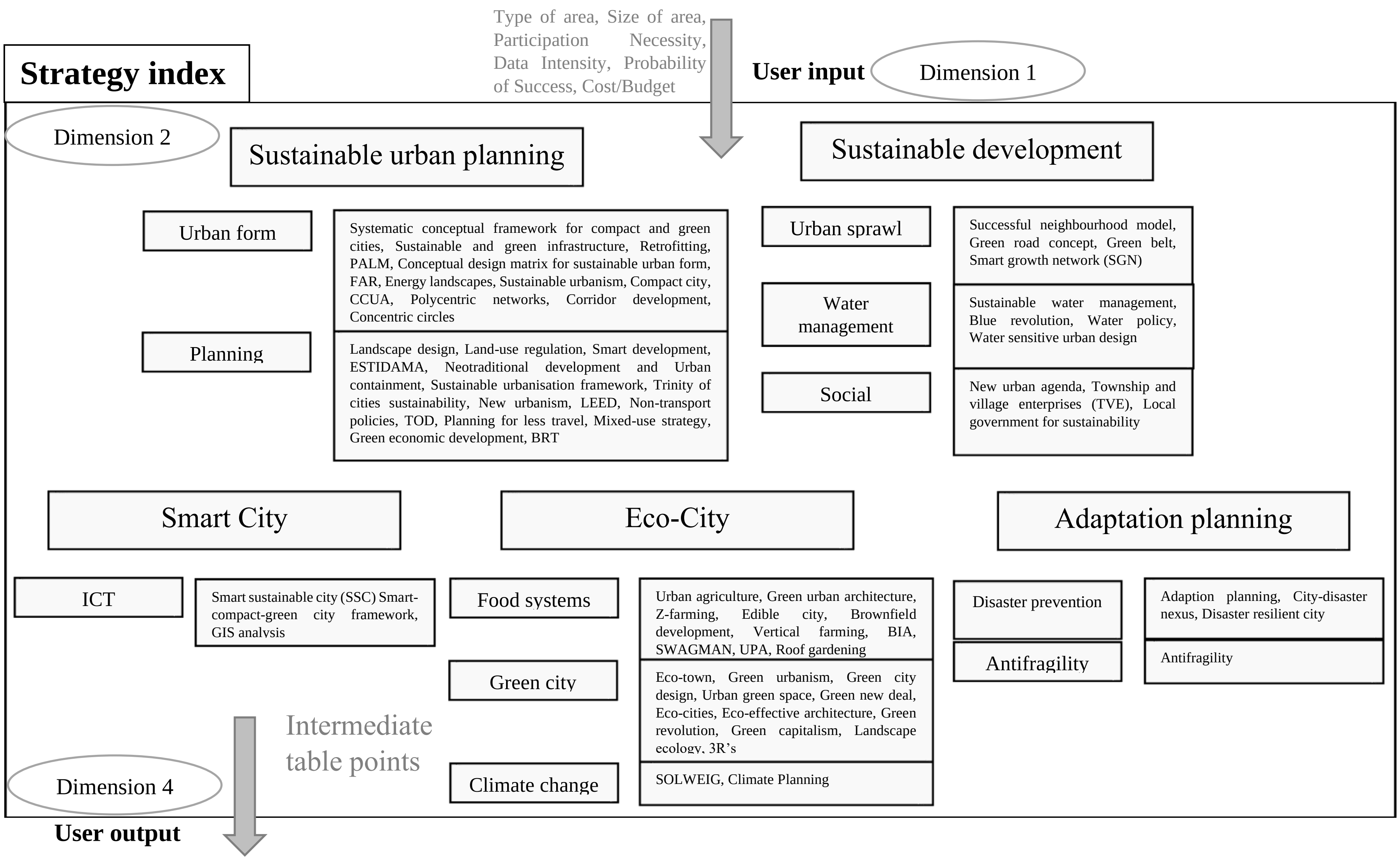



*Figure 7.5: The sustainable urban planning assistant – Strategy index (Source: Author)*

Figure 7.5 illustrates the strategy index, as well as the data entering the strategy index, such as the 6 user input conditions mentioned in Section 7.3.1. The data that leaves the strategy index relates to the intermediate points that have been added to the intermediate table. Thereafter, the points are used to rank the tools/techniques, and to finalise the user output. Examples of how this works will be elaborated in the case studies conducted in Sections 8.5, 8.6 and 8.7.

### 7.3.3 Dimension 3: Triple bottom line balancing

The MCDA, forms part of the triple bottom line balancing / Dimension 3, was developed to identify differences in the numerical weighting of the various tools and techniques. In Chapter 4, the MCDA used a pairwise comparison and weighting method to develop the triple bottom line scores, which were summarised in Table 4.8. These scores were first determined from the AHP, which gave individual scores to each of the tools and techniques in order to differentiate between them. Dimension 3 is connected to Dimension 1, in which the user input is captured and compared to the tools and techniques within the strategy index as well as being compared to the triple bottom line scores set out in Table 4.8 to identify an appropriate tool/technique to satisfy the As-is and To-be requirements. The functional flow block diagram that illustrates these functions can be found in Figure 6.3 of the previous chapter. Using a part of the process flow found in Figure 6.3,

Figure 7.6 illustrates how the triple bottom line scores are filtered from the background logic, before being added to the intermediate table. Thereafter, the points are used to rank the tools/techniques, and finally to generate the user output.

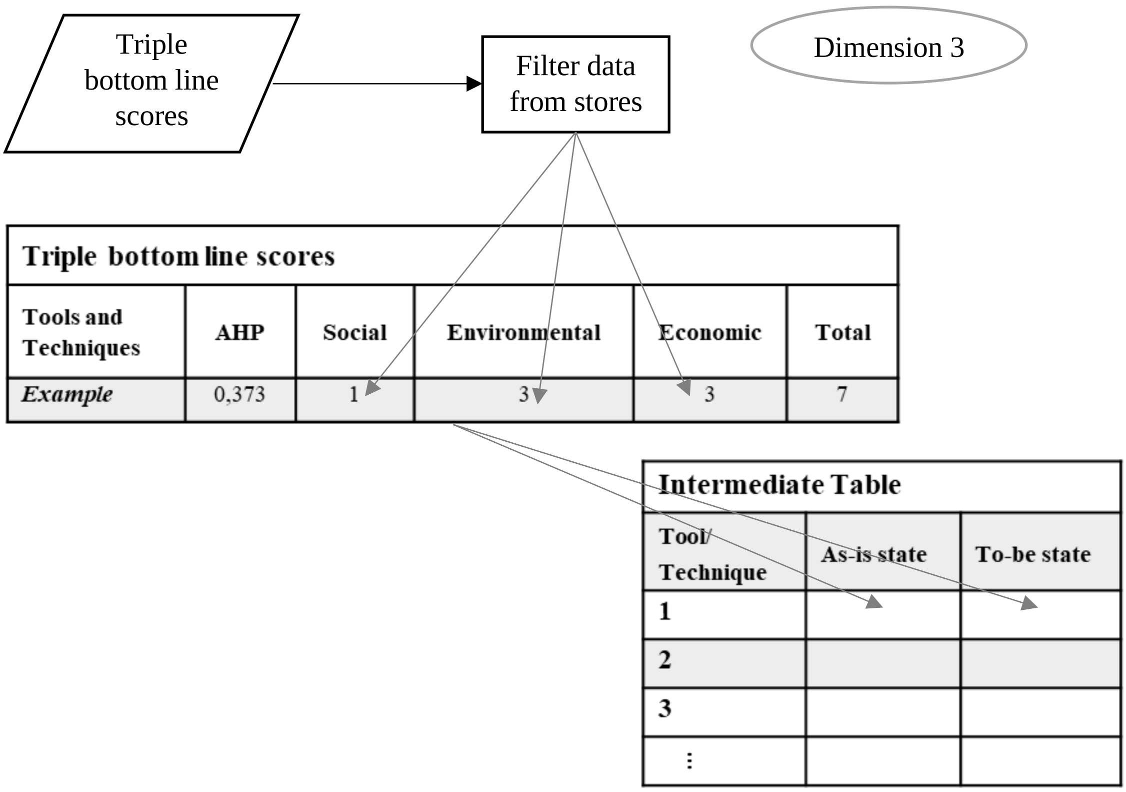



*Figure 7.6: Process flow breakdown of Dimension 3 (Source: Author)*

The AHP scores were then subjected to the scale summarised in Table 4.7. This scale set out the triple bottom line scores, by dividing the points among the three sustainability states (social, environmental and economic). If a tool/technique covered all three states simultaneously, the tool/technique would be classified as a balanced state. These states are illustrated in Figure 7.7. Examples will be discussed in the case studies conducted in Sections 8.5, 8.6 and 8.7.

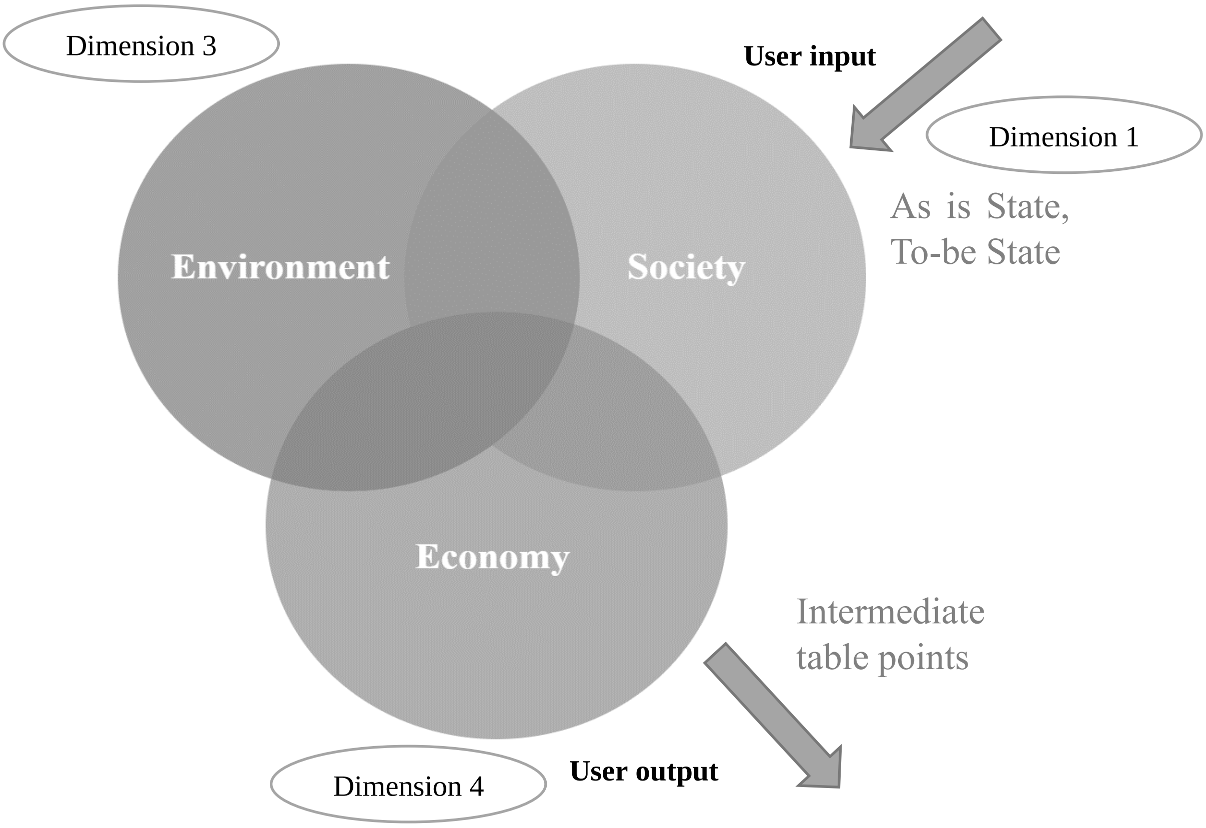
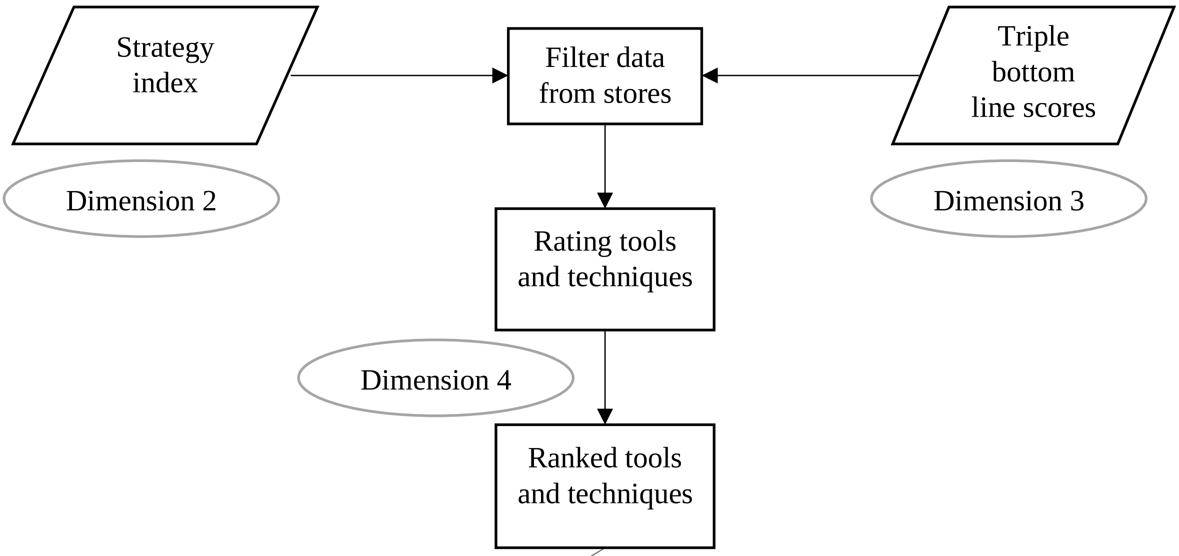



*Figure 7.7:Triple bottom line balancing (Source: Author)*

### 7.3.4 Dimension 4: User output

The final dimension of the SUPA DSF is the user output. In this dimension the tool/technique that is appropriate for the urban planner given the user's requirements. The purpose of this dimension is to gather all the applied data (i.e. rating and ranking of the tools and techniques according to user input and the triple bottom line scores) from the previous three dimensions. Thereafter, combining and evaluating the user input data, tools/techniques criteria and triple bottom line scores to determine an overall score. The process flow chart of Figure 6.3 can be broken down again to explicitly show the processes in conjunction with the dimensions. Figure 7.8 shows an overview inspection of the ranking process of the compiled intermediate table. All the points are tallied up to calculate a total. The tool/technique with the highest total will be the strategy presented to the user as appropriate for achieving the sustainable project goals.




**Compiled Intermediate Table**

| Tool/ Technique | Type of Area | Size of Area | Data Intensity | Participation necessity | As-is State | To-be State | Cost/ Budget | Probability of Success | Total |
|---|---|---|---|---|---|---|---|---|---|
| *Example 1* | 1 | 1 | 1 | 1 | -2 | 8 | 0 | 1 | 11 |
| *Example 2* | 1 | 1 | 1 | 1 | -2 | 6 | 1 | 0 | 9 |
| *Example 3* | 1 | 0 | 1 | 1 | -3 | 7 | 0 | 1 | 8 |

*Figure 7.8: Process flow breakdown of the ranking in the compiled intermediate table*

The ranking functional block flow diagram, including the presentation procedure that outlines how the as-is and to-be states contribute to the additional points to the intermediate table, can be found in Figure 6.6. Each criterion (i.e. as established under Section 7.3.1) will be addressed by a brief description stating the best implementation option for the selected tool/technique, as shown in Table 7.1.

*Table 7.1: User output example sheet*

| **Tool/Technique: (Example)** | | |
|---|---|---|
| Criteria | | Conditions |
| 1. Type of Area | | Residential |
| The *example* matches the Residential urban system element. Therefore, in order to implement this effectively, the user can focus on housing that has access to basic human needs and services and, furthermore, on the fact that the residential areas need to access affordable and reliable sustainable renewable energy sources. | | |
| 2. Size of Area | | City Wide |
| The *example* matches the Size of Area. Therefore, in order to implement this effectively, the user can encourage cooperation among urban areas and promote urban-rural partnerships for performing services locally and regionally. | | |
| 3. Participation Necessity | | Governmental |
| The *example* matches the Participation Necessity. Therefore, in order to implement this effectively, the user can support the policies and legislation to gain greater transparency and develop sustainably and, furthermore, through cooperation, to meet all relevant stakeholder needs. | | |
| 4. As-is State | | Environmental |
| The *example* matches the As-is State. Therefore, in order to implement this effectively, the user can capture the data for the positive environmental impacts currently in place. | | |
| 5. To-be State | | Environmental and Economic |
| The *example* matches the To-be State. Therefore, in order to implement this effectively, the user can prioritise infrastructure design to drive cost and resource reduction, and furthermore, encourage urban-rural interactions to maximise local productivity. | | |
| 6. Data Intensity | | Quantitative |
| The *example* matches the Data Intensity. Therefore, in order to implement this effectively, the user can ensure the data is captured proficiently and furthermore, ensure plans are conducted with prominence to data-driven results. | | |
| 7. Probability of Success | | Medium |
| The *example* does not match the implementation difficulty. Therefore, in order to implement this effectively, the user can source experts in the example to increase the likelihood of success of the project, and furthermore, to reduce risk with data-driven decisions. | | |
| 8. Cost/Budget | | Minimal |
| The *example* matches the Cost/Budget. Therefore, in order to implement this effectively, the user can interact with governmental broad-based and well-resourced permanent mechanisms that are open to all to reduce costs, and furthermore, implement anti-corruption measures that promote financial security and integrity. | | |
| *Reiteration indicator: A reminder to execute the SUPA DSF after 12 months after initial use. Using the to-be state of current project as the new user input for reiteration.* | | |
| *Source:* (United Nations (Habitat III), 2017) | | |

The user output sheet in Table 7.1 shows which tool or technique is presented by the framework. It also shows each condition that was selected by the user. Thereafter, it offers guidance to the user with regard to each criterion, depending on whether the tool/technique matched or not. This guidance will thus support the user in finding the best practices for implementing the recommended tool or technique, or it will advise the user if the tool/technique does not follow exactly the user's context. The user output should not be the final assessment, but a reiteration indicator is added to remind the user to reuse the tool with new inputs in order to elicit continuous improvement.

The feasibility and applicability of the final provided tool/technique for the sustainable urban planning project should be investigated by the user within his or her specific context. This extra step is necessary because the SUPA DSF does not assess the operational or financial requirements in depth for real-world implementation of the recommended tool or technique.

### 7.3.5 Diagrammatic representation of the SUPA DSF

The conceptualisation of the SUPA DSF is discussed in this subsection. Figure 7.9 illustrates how the dimensions interact with each other, and furthermore how the specific data moves from one dimension to the other. Lastly, the processes pertaining to each dimension are briefly described.

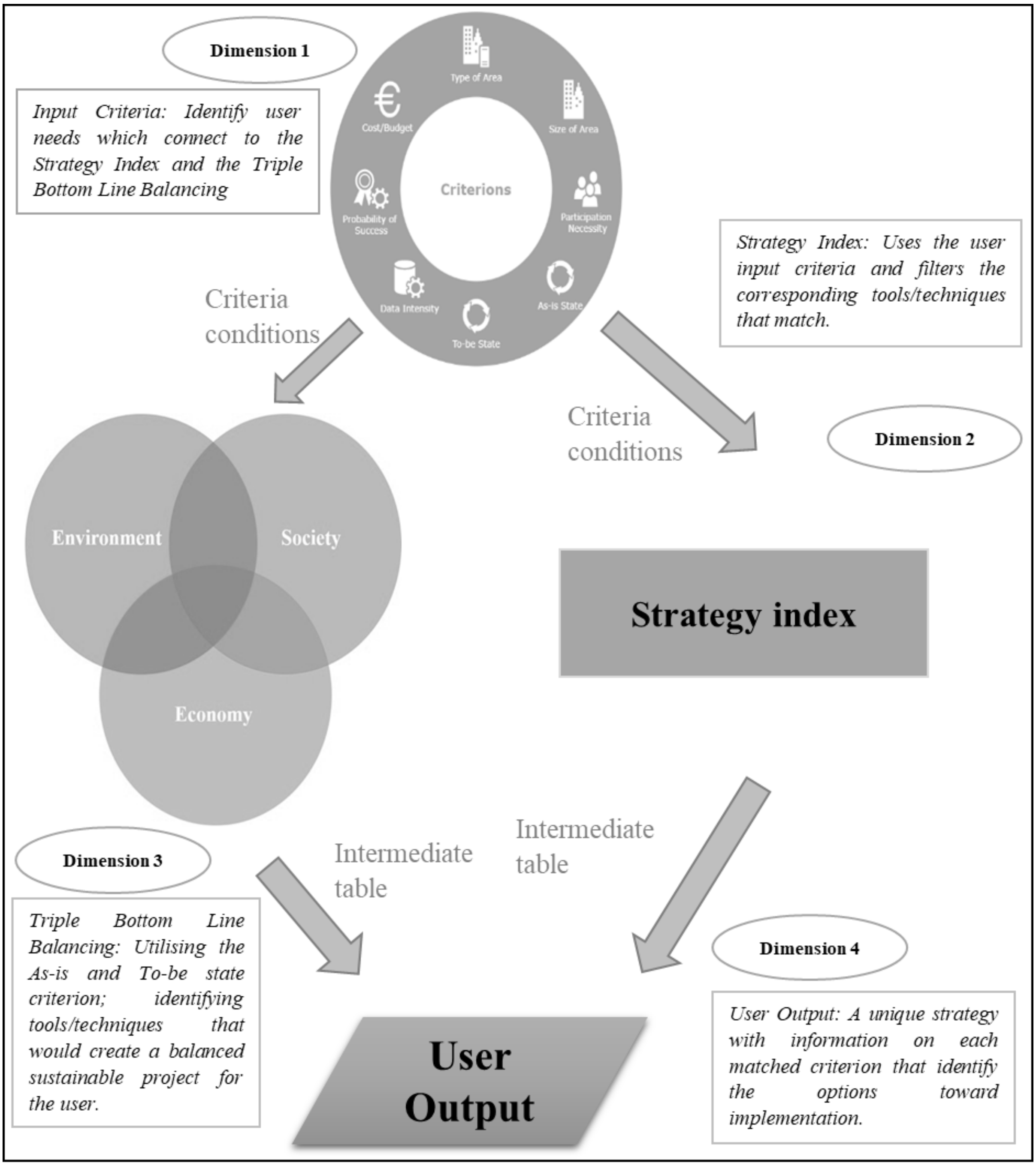



*Figure 7.9: Diagrammatic representation of the SUPA DSF (Source: Author)*

## 7.4 Conclusion: Chapter 7

This chapter presented Part A of the final phase of the systems engineering approach. The design synthesis was conducted with the aim of developing a DSF that is able to contribute to sustainable urban planning in developing countries. As explained in this chapter, the SUPA DSF consists of 4 dimensions, which relate to the steps followed in selecting an appropriate tool/technique to assist urban planners with their sustainable projects. The following chapter presents Part B of the design synthesis, and also verifies and validates the SUPA DSF by evaluating the requirements specification, conducting SME interviews, and assessing case studies in relation to the SUPA DSF.

Chapter 8 will thus focus on the evaluation of the SUPA DSF, and this evaluation will consist of two parts, namely, verification and validation.

# Chapter 8: Verification and validation of the sustainable urban planning assistant decision support framework

In order to ensure that the developed research product contributes toward the successful transitioning of cities towards sustainability, the research must investigate the relevance of the Sustainable Urban Planning Assistant Decision Support Framework (SUPA DSF) in real-world situations. In this chapter the development of an evaluation strategy with verification and validation outcomes are discussed, and case studies, that cover three sustainable urban planning challenges is outlined. Finally, any refinements made to the SUPA DSF in response to feedback from subject matter experts (SMEs) and insights gained form the case studies are discussed.

The evaluation strategy begins with the verification process of evaluating the requirements specification and then performing a theoretical verification by means of SMEs. Lastly, the validation procedure is conducted with three case studies focusing on the sustainable urban planning challenges identified in the systematic literature review. The final part of the last phase of the systems engineering approach, the verification and validation process, is described in this chapter (see Figure 8.1).

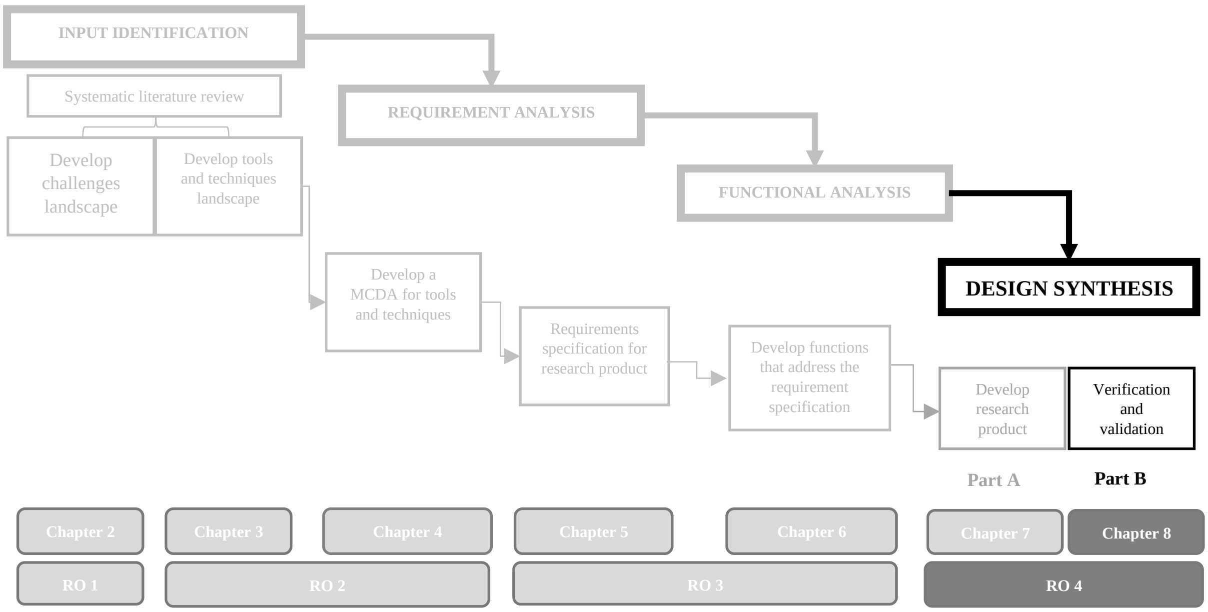



*Figure 8.1: Thesis schematic (Chapter 8)*

## 8.1 Verification of the SUPA DSF

The verification of the requirements and how they satisfy the framework demonstrates whether the framework has followed the guidelines and restrictions provided by the requirements specification. The evaluation strategy consists of two parts: verification and validation.

The first part of the evaluation strategy, i.e., verification of the SUPA DSF, consists of two stages: (i) evaluation of the requirements specification, and (ii) theoretical verification of the framework.

Verification is a method of inspecting, approving, ensuring, and being confident in an approach used (Morse *et al.*, 2002). Applying verification strategies is fundamental to guiding research inquiries (Morse *et al.*, 2002). Ensuring consistency by using strategies is essential for each qualitative project and integrates the responsibility for maintaining reliability and validity with the judgements of external reviewers (Morse *et al.*, 2002). The purpose of the verification process in this study is thus to verify whether the framework can produce an appropriate tool or technique for increasing the sustainability of an urban system.

The second part of the evaluation strategy is the validation of the SUPA DSF. The validation consists case studies regarding the three sustainable urban planning challenges uncovered in Chapter 2, namely, urbanisation, urban sprawl and population growth. Therefore, three separate case studies will be conducted to validate the SUPA DSF for relevancy and practicability. These verification and validation strategies are discussed in the following sections.

### 8.1.1 Verification approach

In order to verify whether the framework produces an appropriate tool/technique to increase the sustainability of an urban system, two stages are needed. The first stage evaluates the requirements specification (Chapter 5) and whether this achieves the proposed aim and objectives of the research. This is followed by the presentation of a theoretical verification to SMEs of the SUPA DSF, which satisfies the theory of development for the framework. In particular, the evaluation identifies and develops a framework that contributes to the successful transition to better sustainability of a city, by mitigating the challenges and safeguarding the future prosperity of urban planning practices in developing countries, and balancing the social, environmental, and economic stability of urban systems. Finally, the chapter refines the SUPA DSF in response to feedback from the SMEs.

### 8.1.2 Overview of requirement specifications evaluation

The first part of the verification strategy is an evaluation of the stated requirement specifications. The SUPA framework has been developed using a quantitative comparative ranking system in order to deliver results. The output of this framework is the most appropriate tool/technique to be implemented for the given urban planning project. A self-evaluation will be completed by the researcher by assessing the requirements specification within three segments: clarification, purpose and development discussed in Section 8.2. The summary for the verification strategy is shown in Table 8.1, and the self-evaluation is discussed in Section 8.2.

### 8.1.3 Overview of theoretical verification

The literature and information included in Chapter 5 (Requirement Specifications) and Chapter 6 (Functional Requirements) must be assessed by SMEs to determine whether these assumptions and data are adequate to produce the proposed DSF. The aim is for SMEs to confirm whether alternative literature or methods could increase the framework's capability to support sustainable urban planning within the given context and scope. The SME assessment must be completed by means of a questionnaire, which SMEs are to complete after they have been presented with a document introducing and explaining the development of the framework.

*Table 8.1: Summary of verification strategy*

| Verification Stage | Perspective | Contents area |
|---|---|---|
| **Requirements Specification** | Self-evaluation. | Requirement specification (Chapter 5) |
| **Theoretical** | Subject matter experts verifying theory is satisfactory for framework development. | (Chapter 5) & Functional requirements (Chapter 6) |

## 8.2 Evaluation of requirements specification

The design framework is based on the roles it plays in the segments that dictate the transformation of an urban system, i.e., the segments of classification, purpose and development (Kennon, 2017). The framework stops short of the implementation stage of the sustainable project for the user. Table 8.3 to Table 8.7 group the functional requirements, user requirements, design restrictions, attention points and boundary conditions per segment of the urban system. Monitoring the requirements specification requires a structured approach. Table 8.2 defines the three segments in terms of the objective, responsibility, and considerations of the specific urban system. Therefore, the verification of the requirements specification will be evaluated according to this approach in order to assess whether the proposed framework adheres to the aim of the research study.

*Table 8.2: Monitoring requirements specification verification. Source: (Kennon, 2017)*

| | Classification Segment | Purpose Segment | Development Segment |
|---|---|---|---|
| **Objective** | Understand the current urban system presented from the user's context. | Reach stated aim for the urban system proposed by user. | Provide tool/technique with the best chance of achieving the 'To-be' state from the 'As-is' state. |
| **Responsibility** | Evaluate the user's input according to the criteria and corresponding interaction with tools/techniques. | The implementation strategy should attain the user's sustainable state. | Evaluate the current urban system against all the solution-specific tools/techniques with the matching criteria to allow for the best outcome. |
| **Urban System Considerations** | Present a systematic view of the urban system that allows multi-criteria evaluation of the current user system. | Tool/Technique applied should adhere to the required sustainable state. | Identify implementation strategies that improve the urban system by encouraging a balanced sustainable state according to the Triple Bottom Line scores. |

### 8.2.1 Functional requirements verification

The verification of the functional requirements requires outlining the demands of the research product. The functional requirements, as listed in Section 5.1.1, Table 5.1, are linked specifically to the features that have been analysed in the previous chapter (Huff, Tranfield and Van Aken, 2006). In the case of a tick mark displayed, it denotes that these requirements have been covered within the segment(s).

*Table 8.3: Verification of functional requirements*

| Requirement ID | Requirements of the research product | Classification | Purpose | Development |
|---|---|---|---|---|
| F1 | Improve the social, environmental, and economic stability of urban planning projects. | | ✓ | |
| F2 | Suggest tools/techniques to assist with and enable improved sustainability. | | ✓ | |
| F3 | Capture the user's data relating to eight criteria with several conditions for the research product to conduct evaluations. | ✓ | | |
| F4 | Evaluate the user input using a ranking system. | ✓ | | ✓ |
| F5 | Suggest related tools/techniques that support the user's objectives. | | ✓ | ✓ |
| F6 | Support continued and repeated usage. | | | ✓ |
| F7 | Able to identify a set of candidates for consideration. | ✓ | | |

### 8.2.2 User requirements verification

The user requirements, as set out in Section 5.1.2, Table 5.2, are characteristic of the SUPA DSF. The user requirements are not linked to specific features within the framework, but are addressed by the framework in its entirety, as shown in the table below (Huff, Tranfield and Van Aken, 2006). The requirements in Table 8.4 are mostly conceptual. They do not specifically provide requirements in the design of the research product. However, the user requirements do need to be verified to ensure that the framework development is conceptually satisfied.

*Table 8.4: Verification of user requirements*

| Requirement ID | Requirements of the research product | Classification | Purpose | Development |
|---|---|---|---|---|
| U1 | It should be user friendly. | Users are guided through the framework with simple instructions till the desired outcome is produced. | | |
| U2 | The user should be able to apply their own discretion within the scope. | Users will be in control of each stage of the framework with guidance from the designer. Examples will be provided to assist within the input stages. | | |
| U3 | It should be considered as a kind of management support. | Management forms part of the users of the framework, and entails identifying information that would otherwise not be available. | | |
| U4 | It should choose the appropriate candidates according to the evaluations. | ✓ | ✓ | |
| U5 | It should provide references to enable the user to find the supporting paper that corresponds to the identified tool/technique. | The framework will display supporting papers with references in the output stage for further exploration and explanation if the user requires more information. | | |

### 8.2.3 Design restriction verification

The design restrictions, as provided in Section 5.1.3, Table 5.3, are characteristic of the SUPA DSF. The design restrictions are not, in each case, linked to specific features within the framework, but could be theoretically fixed throughout the framework, as shown in the table below (Huff, Tranfield and Van Aken, 2006).

*Table 8.5: Verification of design restriction*

| Requirement ID | Restrictions | Classification | Purpose | Development |
|---|---|---|---|---|
| D1 | It is not the intention of the research to develop new technology. | The framework is provided to reduce the gap between theory and reality of sustainable urban planning practices. There is nothing within the framework that is new/radical in the field urban planning. It merely uses a new method of defining the current technology to quantify the differences. The framework differentiates between the appropriate tool/technique for the user. | | |
| D2 | A high level/strategic approach for the research product should be the first method of the solution. | | ✓ | ✓ |
| D3 | Any combination of user input needs to generate a result. | | ✓ | ✓ |
| D4 | The research product is not a legal or legislative guide. | The framework assumes that the user knows the legislative requirements for their decisions. Otherwise, they would know when to seek professional assistance from a specialist. | | |

### 8.2.4 Attention points verification

The attention points, as provided in Section 5.1.4, Table 5.4 are characteristic to the SUPA DSF. The attention points are linked to specific features within the framework, where they may have been satisfied in the development of the framework, as seen in the table below (Huff, Tranfield and Van Aken, 2006).

*Table 8.6: Verification of attention points*

| Requirement ID | Attention points | Classification | Purpose | Development |
|---|---|---|---|---|
| A1 | The approach should reflect early best practice within an evolving field of knowledge. | | | ✓ |
| A2 | Developing countries lack expertise and data availability. | | | ✓ |
| A3 | The solution should not be more specific than is essential. | | | ✓ |

### 8.2.5 Boundary conditions verification

Boundary conditions must be met unconditionally for the research product design to succeed. The requirements have been compiled to outline ensure who is responsible and where the boundaries of application lie for the research product (Huff, Tranfield and Van Aken, 2006). These were not linked to specific features in the framework. However, related to the theoretical conditions, as seen in the table below.

*Table 8.7: Verification of boundary conditions*

<table>
<tr><th>Requirement ID</th><th>Boundary conditions</th><th>Classification</th><th>Purpose</th><th>Development</th></tr>
<tr><td>B1</td><td>The study has done as much as is capable to reduce bias and remain ethical when judging differences between different tools and techniques with regard to their influence on sustainable urban planning in developing countries.</td><td colspan="3">The framework should be used for the purpose of guiding the user toward more balanced sustainable urban planning. Any use beyond this will be solely in the control of the user. Experts other than urban planning professionals should be consulted in order to address any legal concerns</td></tr>
<tr><td>B2</td><td>Temporal and spatial scales within the assessment of deciding the appropriate tool/technique for a sustainable urban planning project come as close to accuracy in the real world as the systematic literature review provides.</td><td colspan="3">The literature will become outdated along temporal and spatial scales as new tools/techniques are developed. The current framework would need to be verified and updated for continued use.</td></tr>
<tr><td>B3</td><td>This study is not responsible for decisions made by the users.</td><td colspan="3">The business environment is competitive and may affect competitors of the users. The framework is based on legal and ethical principles.</td></tr>
<tr><td>B4</td><td>The research product only provides insight into possible strategies to achieving more balanced sustainable projects.</td><td colspan="3">The framework operates on a non-biased foundation. The value created should improve the balanced sustainability of urban planning projects, if applied correctly.</td></tr>
</table>

The objective of the requirements specification is to identify the requirements, restrictions and boundaries relating to a research product that achieves the aim of the research. The aim of this particular research is to develop a research product that contributes to the successful transition of city sustainability, to mitigate the challenges of urban planning and safeguard the future prosperity of cities, especially in developing countries, by supporting a balance between the social, environmental, and economic stability within an urban system.

### 8.2.6 Findings and refinements of requirements specification evaluation

Each requirement stated as a user requirement, functional (essential or desirable) requirement, design restriction, attention point or boundary condition has been addressed in the previous section. Each of these requirements was compared either to a specific stage within the framework or the use of the framework conceptually. These were verified to have been satisfied by the framework, its use, and its intention.

## 8.3 Theoretical verification

An interview process was conducted in two steps: first, the SMEs were given a document to read before the interview, introducing the background of the SUPA DSF and explaining its development, and then an online / virtual interview was conducted with each of the SMEs separately, which comprised a presentation followed by a questionnaire (the pre-read document and presentation can be found in Appendix B). For an overview of the qualification and background experiences of the different SMEs who assisted with the theoretical verification, see Table 8.8.

*Table 8.8: SME qualification and background information*

| SME number | Degree/Qualification | Background experience |
|---|---|---|
| 1 | Hons B Com; Hons B. Ed; Project Management; PGDip in Futures Studies; MPhil in Futures Studies | Senior Futurist at Institute for Futures Research (2017 to the present)<br>Lead Consultant at DV Consulting (2008 to the present) |
| 2 | PhD in Business Administration and Management | MBA programme head of USB (from 2016 to the present)<br>USB Executive Development Facilitator (2006 – 2016)<br>Senior Lecturer: Strategy & Sustainability of USB (from 2005 to the present) |
| 3 | Environmental Studies with Honours; Master's in City/Urban, Community and Regional Planning | Transit Programming Support Specialist (from 2020 to the present)<br>Project Coordination Unit Intern (2019 – 2020)<br>Intern at Clarion (2019 – 2019)<br>Nashville Promise Zone Vista Leader at AmeriCorps (2017 – 2018) |
| 4 | B.A.; MBA in Management Information Systems; MSc in Climate Change and Sustainable Development; PhD in Public Planning and Development Management | Doctoral Student at Stellenbosch University (2017 to the present)<br>Business Development and Market Analyst at Makeduconsult (2012 – 2016)<br>ICT/IB ITGS Tutor at SOS-Hermann Gmeiner International College (2011 – 2013) |
| 5 | MSc in Economics for Development, environment, carbon, economics; MSc Environmental Change and Management | Director of Econologic (from 1998 to the Present)<br>Associate at Stockholm Environment Institute (2006 to the present)<br>Director of Credible Carbon (from 2007 to the present)<br>Economist at African Centre for Cities (from 2010 to the present) |

### 8.3.1 Theoretical verification questionnaire

A 5-point Likert scale was used to rate the responses to the questions. In the following section, the results from the validation process are presented, with an overview of the different recommendations that were made. The first five questions made use of a 5-point Likert scale, to gain a holistic overview of the framework, the terminology and intuitiveness to understand the concepts of the framework, and the targeted audience group. The Likert scale key can be found in Table 8.9 along with a summary of the first seven questions.

From the results of Question 1, with regard to the research containing an improved understanding of sustainable urban planning, the elements, challenges and methods identified were regarded as sufficient for the assessment. Four respondents agree that the research has facilitated a thorough understanding of sustainable urban planning, but one SME asked for a more in-depth understanding of the context in the decision-making process for urban planning in developing countries.

With regard to Question 2, the SMEs agreed that the requirements specification would meet the objectives of the research, and mentioned that the requirements were handled effectively in the functional analysis of the research, and that the framework would help with decision making.

In connection with Question 3, relating to the user input dimension and whether the eight criteria were sufficient to capture all the necessary information for the assessment, the SMEs agreed that the criteria would capture more than enough for a sustainable project. More implicit distinctions were, however, needed to differentiate between the qualitative and quantitative tools/techniques, and they recommended that there should be a combination of both data types.

With reference to Question 4, the SMEs were satisfied with the urban planning spectrum covered by the 13 units of observation along with the 70 solution-specific tools/techniques. A comment was made regarding the lack of a unit of observation for energy management. This was a topic that was identified in the literature review. However, many of the energy management topics were covered in the planning or urban form units of observation.

Concerning Question 5, the SMEs agreed that the triple bottom line balancing was a good method of assessing sustainable urban planning. However, they also commented that the scores generated by the MCDA for the triple bottom line balancing leave too much room for interpretation, in that other experts would see the tools or techniques differently. Subjectivity is apparent in many decision support frameworks. To reduce such bias, the triple bottom line balancing should target the difficult conversations that would lead to trade-offs. Such as conversations about balancing the need for sustainability and the costs of such tools and techniques.

Question 6 referred to the user output of the SUPA DSF and whether this was sufficient for the user. Most of the SMEs agreed that the generated responses would be enough to allow urban planners to continue with the implementation of a sustainable project. However, some commented that the outflow of information should not be binary but that it should include contextual differences. Such as creating a personal reference to the project that was presented. But this would be out of the scope for a high level DSF.

Finally, with regard to Question 7, the experts were all in agreement that the SUPA DSF would improve decision making relating to sustainable urban planning in developing countries. Furthermore, they referred to the framework as useful assistance for training urban planners.

*Table 8.9: SME verification results for Questions 1-7*

| **Likert Scale Key** | | | | |
|---|---|---|---|---|
| Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
| | | | | |

| Questions | SME 1 | SME 2 | SME 3 | SME 4 | SME 5 |
|---|---|---|---|---|---|
| i. Does the research contain all the applicable context-specific elements (challenges, methods, and requirements) to assist in understanding sustainable urban planning in developing countries? If not, could you provide any guidance on additional elements? | | | | | |
| | | | | | |
| ii. Will the requirements specification achieve the research objective? | | | | | |
| | | | | | |
| iii. For the User Input dimension, are the 8 criteria sufficient to capture all the necessary information for assessment? If not, could you provide alternatives that could be considered for inclusion? | | | | | |
| | | | | | |
| iv. For the Strategy Index dimension, are the 13 units of observation sufficient to cover the urban planning spectrum? | | | | | |
| | | | | | |
| v. For the Triple Bottom Line Balancing dimension, has this method of analysis contributed to the overall result of the framework outcome? | | | | | |
| | | | | | |
| vi. User Output dimension was explained in the functional flow block diagram; was the approach of generating responses sufficient for user output? | | | | | |
| | | | | | |
| vii. Could the SUPA framework contribute toward improving sustainable urban planning in developing countries? | | | | | |
| | | | | | |

## 8.3.2 Findings and refinements of theoretical verification

During the verification process, the SMEs made certain recommendations regarding the SUPA DSF. These recommendations were considered, reviewed and addressed by either adapting the framework or by proposing possible future work when such recommendations fell outside the scope of the research. The discussion of this can be divided into the following three categories, i.e., limitations, inclusions and exclusions.

### *8.3.2.1 Limitations*

One limitation that emerged from interviews concerns the challenges associated with qualitative versus quantitative tools/techniques. there is insufficient data on how social issues or environmental impacts of the tools and techniques proposed by your framework are improved when implemented. Consequently, for this research, a high level/strategic approach differentiated between the social, environmental and economic states for each tool/technique, by providing a quantitative decision support framework for developing countries.

The context is important for any framework. According to the SMEs, the research would be more credible if the researcher incorporated an understanding of the fundamental constraints facing local governments in many African countries. These constraints include an inadequate budget to make improvements, in addition to a lack of decision-making power. This refinement will be included in the research scope of Chapter 1, Section 1.6.

An additional concern regards public participation. The use of the SUPA DSF is not an ideal method for solicitating input for planning urban structures. However, the context of public participation is covered in Section 7.3.1.4. The public's assistance is purely cooperation based and used as a source of qualitative data for more input for the tools/techniques. The public would not be involved with the planning of construction. This is amended in Section 7.3.1.4.

According to the SMEs, the framework is sophisticated, with a holistic approach. If a user were to use the framework, they would gain a generalised sense of more options being available that could improve sustainability. This is because it incorporates 70 tools/techniques that users may not have considered. The framework thus draws the user's attention to different ways of approaching urban planning. It moreover directs the user along a specific path in the hope that this will enable him/her to achieve the sustainable goals of the project.

#### *8.3.2.2 Inclusions*

A comment referring to what happens after the SUPA DSF is used in a urban planning project. It was indicated in the requirements specification that the framework would be viable for continued and repeated use. However, the user must be reminded to reiterate the framework with the updated 'to-be' state of the framework as the updated 'user input' after a period of time. This reminder will assist the user to pursue continuous improvement for their project. This refinement is included into the user output of the framework and is shown at the bottom of the case study outputs for Table 8.12, Table 8.15 and Table 8.18.

#### *8.3.2.3 Exclusions*

An SME raised the concern that emerging challenges from urbanisation, urban sprawl and population growth, for instance, might be missed because the SUPA DSF focuses only on major challenges. And that this is why it is important for the user to provide their context. This comment is useful but outside of the scope of this research.

A cautionary comment was not to say population is a problem, the consideration is controversial. Developed countries the resources. But now in a sustainable standpoint, you are also targeting the social aspects. So, with population growth, to adhere to everyone's needs. For that resource provision, the specific needs, were set out by the Sustainable Development Goals by the UN. Number 1 & 2 are zero poverty and zero hunger. There need to be adhered. That is where the framework context was for developing countries. And urban planners try to solve population growth sustainably, by adhering to environmental stability or social equality or economics prosperity.

A criticism raised by an SME on the framework is that there's a quite a high degree of endogeneity. But the framework could just be used to manage trade-offs within the triple bottom line, which would be more focused. This will be included into the future work proposed in Chapter 9, Section 9.5.

## 8.4 Validation of the SUPA DSF

According to the Standard 610 guidelines of the Institute of Electrical and Electronics Engineers (IEEE), validation is the process of evaluating a developed constituent, system or model to ensure that the objectives stated at the start of the development, are accomplished (IEEE Standards Board, 1990). The final phase of systems engineering is the validation of the research product, which in this study is a decision support framework to assist urban planners to implement balanced and sustainable urban projects. The focus of the validation is to determine if the framework is indeed effective at suggesting and reporting viable options that would contribute to a more balanced triple bottom line outcome when implementing urban planning projects in developing countries.

### 8.4.1 Validation purposes

The validation procedure would like to determine whether the SUPA DSF meets the research aim of contributing to the successful transition of a city towards greater sustainability, to mitigate the challenges and safeguard the future prosperity of developing countries in the area of urban planning, and of supporting a balance between the social, environmental, and economic stability within an urban system. To achieve this, there are two purposes for the validation, namely:

i. Evaluating the relevancy of the SUPA DSF, by referring to the applicability in the context of real-world situations,
ii. Evaluating the practicability of the SUPA DSF, by referring to the simplicity and degree to which the framework is easy to comprehend.

### 8.4.2 Validation methodology

The validation process begins by applying the decision support framework to various case studies to record and assess its robustness and overall usability. Retrospective case studies were conducted on the three urban planning challenges uncovered in the systematic literature review presented in Chapter 2. The aim is to determine whether the results from the decision support framework correspond to previously documented cases, and therefore, attempting to establish the effectiveness of the decision support framework by comparing the two sets of outcomes.

The related case must be specifically similar to the aim which the study wanted to achieve. Therefore, there should be a set of criteria to uphold to clarify whether the case study would be appropriate for this research validation process. The case studies are thus analysed to see whether they conform to the following criteria (Mills, Durepos and Wiebe, 2012):

i. The case study should be retrospective in nature;
ii. The information should be available from certified peer-reviewed articles; and
iii. The case should be within the context of improving sustainability within developing countries.

Using these criteria to identify appropriate cases relating to the three urban planning challenges identified in the systematic literature review. Namely: (i) urbanisation, (ii) urban sprawl and (iii) population growth.

## 8.5 Case study 1: Urbanisation

The main reason for applying a retrospective case study is to determine whether the SUPA DSF can effectively evaluate an implementation strategy pertaining to a real-world case. Furthermore, the comparison with the case study also made it possible to determine whether the SUPA DSF would be able to address gaps or suggest advances on the strategy that had been developed and implemented during the relevant case.

The first case study began by looking at a bi-dimensional sustainable urbanisation framework that explored the social, environmental and economic circumstances in the city of Curitiba, Brazil. Much of this case study was developed for the 2016 issue of the *Journal of Cleaner Production*[3]. This reflects the equivalent aim and research objectives for this research study. The case study was conducted in Brazil, a country that is classified as a middle-income developing country. Furthermore, the case is retrospective in nature due to the extensive assessment and analysis conducted at the time. The case of Curitiba fits the criteria for the case of urbanisation.

### 8.5.1 Background of case study 1

The built form of the contemporary city affects people, natural resources, habitat and climate; these effects have worsened with increasing urbanisation around the world (Bibri, 2018). "*Urbanisation puts an enormous strain on the built environment and the underlying systems and processes, i.e. the physical structures and urban infrastructures and the related operations, functions, and services*" (Bibri, 2018, p. 765). The rate of the changes and spread in urbanisation has presented formidable challenges by, for example, placing massive strain on the surrounding environment (Zhang, 2016). Urbanisation also affects all features within an urban system, starting from the inhabitants' need to improve their livelihood. This is not a problem *per se*, however, as this is a natural progression of human adaptation. Spatial distribution can be confirmed by the occupant space shape of human beings, and which can be categorised in terms of urban and rural forms (Zhang, 2016). However, the problem lies more particularly with competition and resource carrying capacity in order to allow for ample and optimal resources for all inhabitants within the surrounding area. This burden falls to the urban planners, who need to structure and restrict development to fulfil the human progression from rural to urban environments. Constant increases in the resource capacity of residential, commercial and business sectors are thus important to ensure that the urban system experiences minimal strain. "*The urban form of living and associated agglomeration economies involve the creation of a surplus in essential goods, process industries, specialized services (accounting and tax advice), public services and the freeing of labour*" (Zhang, 2016, p. 427). Over the past 6 decades, the global rate of urbanisation has grown by 21%, with over 50% of the world's population concentrated in urban areas. It is projected that this percentage will be closer to 60% by 2030 (Department of Economic and Social Affairs, 2014).

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[3] (Zhang, 2016), DOI: 10.1016/j.jclepro.2015.08.036

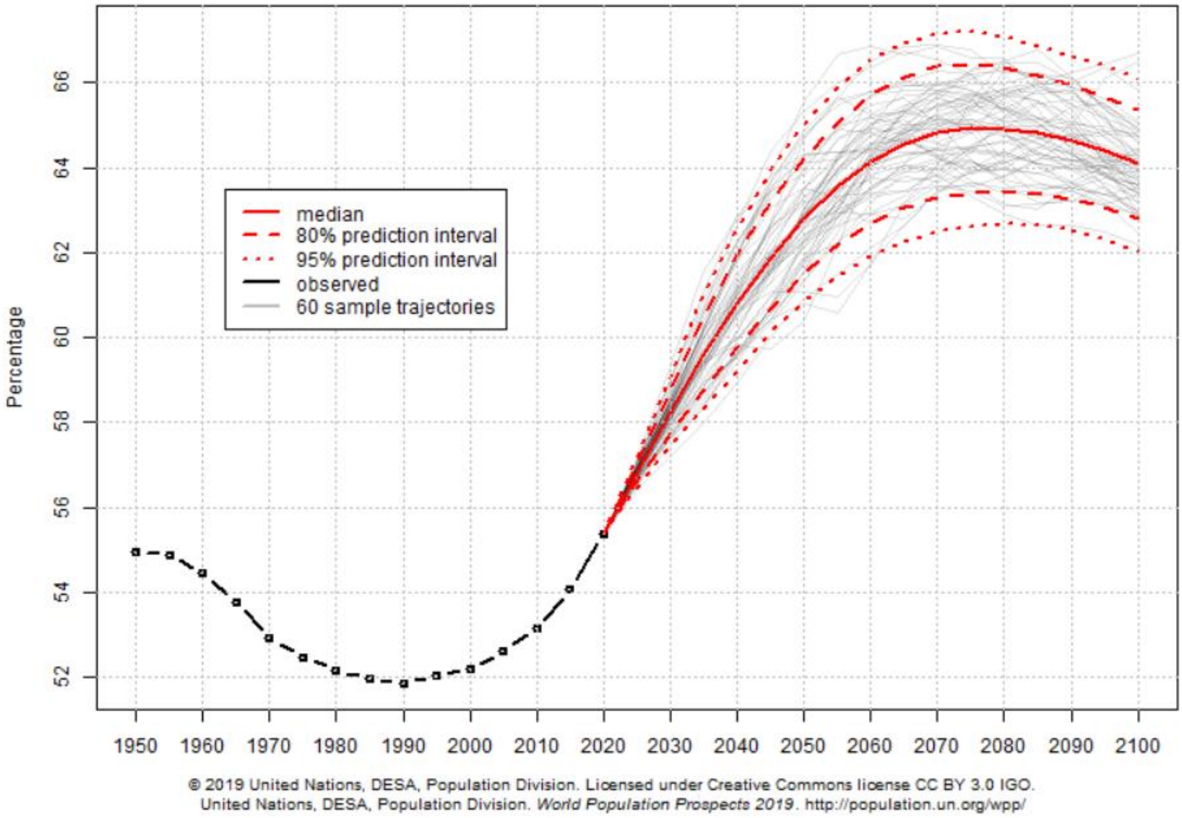


*Figure 8.2: Low income countries (percentage of population aged 15-64 years). Source: (United Nations DESA, 2019)*

Developing countries are faced with many other challenges besides urban planning. However, poor economic management by the government and its subsequent provision of services may be the failing component that has created the massive economic inequality that we see today. The challenges related to rapidly growing urban populations include meeting a massive need for urban infrastructure, and providing effective municipal and social services while also protecting the urban environment (Zhang, 2016). With 1% of the population controlling more than half the global wealth, a statistic that is not decreasing, urban planners need to ensure that urban system resources are directed toward the larger populace, rather than the incentivised capitalists. "*Sustainable urbanization refers to the well-balanced relationship between the social, economic and environmental agents in society*" (Zhang, 2016, p. 427). This perfectly matches the aim of this research study, namely, to create a balanced sustainable urban planning framework. Therefore, in order to ensure the functional capacity of the framework, it needs to be assessed in accordance with the urban planning challenges found in Chapter 2.

In this case study on urbanisation, the city of Curitiba was investigated. Data was obtained from various sources, such as the government, internet, newspaper, articles, books, and media. Content analysis was used to classify and summarise the information contained in the collected data, and the information was coded in accordance with the designed parameters for describing sustainable urbanisation (Zhang, 2016). In Zhang's study, the data were collected in three stages: (i) literature search with content analysis, (ii) 15 personal interviews to ensure validity and to identify barriers for implementing sustainable measures, and (iii) Skype meeting with experts that discussed in-depth the social, economic and environment perspectives of the city of Curitiba (Zhang, 2016).

In that case study, a bi-dimensional model was utilised for sustainable urbanisation. This is a systematic and comprehensive framework that seeks a stable balance between urbanisation and unsustainable development modes (Zhang, 2016). The matrix illustrated in Figure 8.3 below aims to interpret environmental and socioeconomic problems at diverse steps of the growth life cycle from a rural/urban perspective (Zhang, 2016).

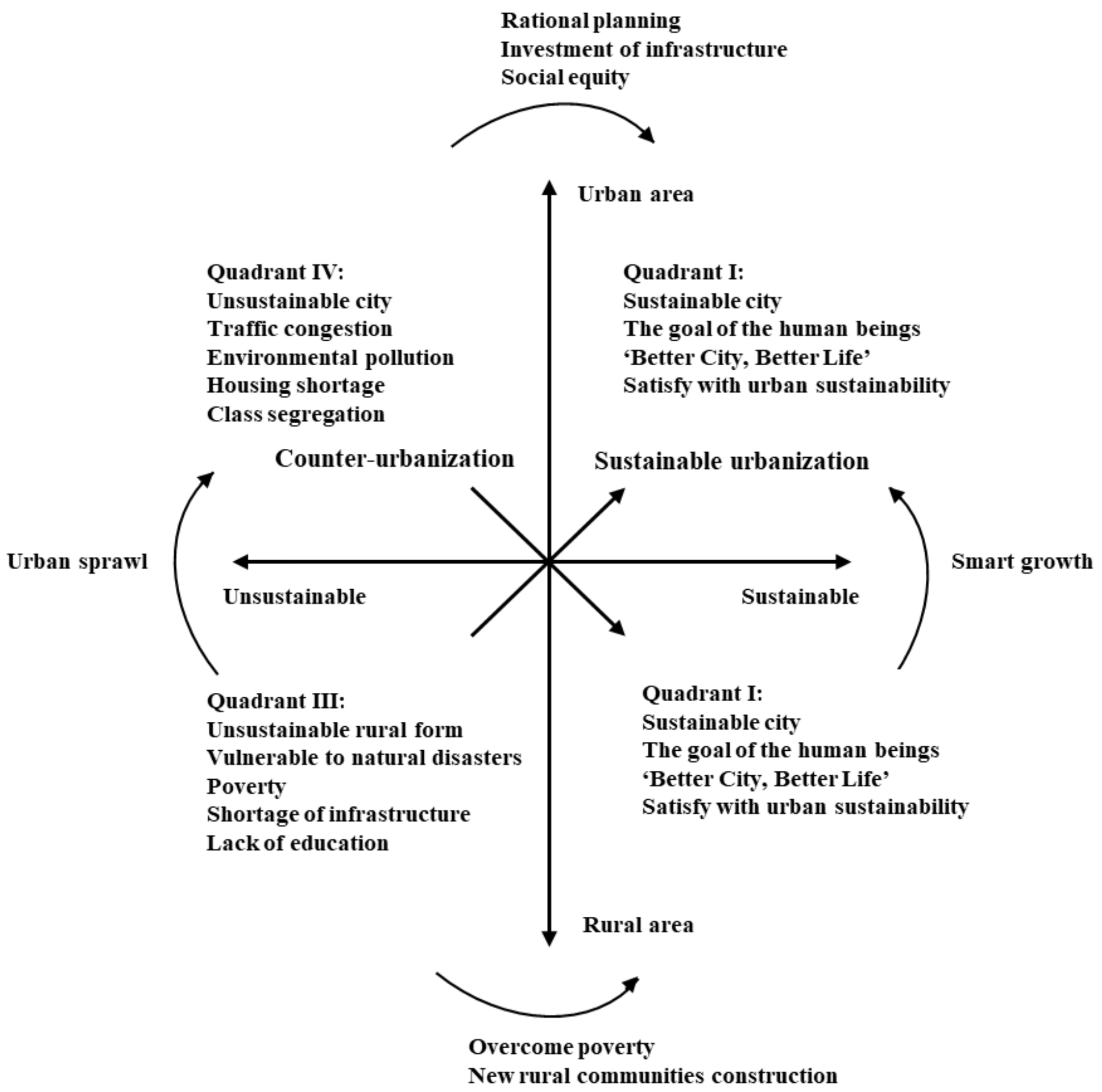


*Figure 8.3: Theoretical matrix for the bi-dimensional model of sustainable urbanisation. Source: (Zhang, 2016)*

The matrix consists of four quadrants: (i) Quadrant 1 (the sustainable city), (ii) Quadrant 2 (the sustainable rural form), (iii) Quadrant 3 (the unsustainable rural form), and (iv) Quadrant 4 (the unsustainable city). There can be transformation between the different stages, e.g. in the case of Quadrant 1 to Quadrant 2, "*driven by factors such as economic development, migration and employment and trade"* (Zhang, 2016, p. 429). In rural areas, there is predominantly industrial development, which needs equal improvement in agriculture (Zhang, 2016). The transformation from Quadrant 3 to Quadrant 2 is difficult. In Africa, the poor are marginalised with regard to substantial shifts in land rights and employment forms (Zhang, 2016). However, advancement in economic conditions, such as education, social infrastructure and employment opportunities, may transform the system to the next quadrant (Zhang, 2016). The last transformational shift is from Quadrant 4 to Quadrant 1, which occurs due to the absence of preparation and attention to sustainability. This degradation of the system can be reduced by implementing renewable resources, housing and law enforcement in new areas of development (Zhang, 2016). These three possible transformations due to urbanisation have all been carefully studied and formulated. The bi-dimensional model for sustainable urbanisation only interprets the 4 different situations of urbanisation causes in relation to urban/rural systems, unlike the SUPA DSF, which identifies the current project information from the user to encourage a balanced sustainable approach. Moreover, for the case study of urbanisation, the bi-dimensional model for sustainable urbanisation is not under investigation. However, the case of Curitiba was investigated with the bi-dimensional model for sustainable urbanisation. So, Curitiba, from the viewpoint of the article[2], needed to be assessed to gather the whole picture of the case.

### 8.5.2 Reality of case study 1

The case of Curitiba[3] was developed and maintained over decades of urban planning projects. Rather than one single strategy being implemented, many methods and approaches were used to contribute to creating Curitiba, which has been classified as a sustainable city (Zhang, 2016). This is considered regarding the SUPA DSF because it only recommends one tool/technique to assist with improving the balanced sustainable project. Furthermore,

Curitiba is located in the south of Brazil in a temperate climate zone, with a geographical area of approximately 435 km$^2$. It is the capital city of the region of Parana, consisting of 26 municipalities and housing a total population of 3.2 million people in 2016. "*From the 1950s-1980s, Curitiba was one of the fastest growing cities in Brazil, facing pressure from rapid growth, inflation and poverty to restructure the city*" (Zhang, 2016, p. 430). In this time, the master plan limited growth in the city area, whilst encouraging commercial activities. "*The green space in Curitiba has a strong link with drainage and flood controls, and the flood-prone area can be transformed into green parks to protect against high risk streams*" (Zhang, 2016, p. 431). This type of planning leans toward more environmental protection and climate change planning tools and techniques. The road structure of Curitiba was based upon a hierarchical system, where each was designed with a specific function in mind that formed a network of highly efficient interlinked routes (Zhang, 2016). The bus system was an especially important factor in the success because 85% of the transit population utilised these buses. Furthermore, transport costs only amounted to around 10% of household income, and the use of such public transport moreover reduced air pollution (Zhang, 2016).

The case study documented the changes implemented in accordance with each triple bottom line. In terms of social equality, a variety of projects were implemented over the years. Providing free educational centres, job training and internet facilities has contributed toward Curitiba having the lowest illiteracy rate in all of Brazil (Zhang, 2016). One of the best examples of achieving a balanced Triple Bottom Line was providing employment for homeless and addicted people in garbage separation plants (Zhang, 2016). The city also promoted environmental protection, social inclusion, and local economic development. With regard to the natural environment, Curitiba is known as the ecological capital of Brazil. The prominent projects include combining waste management with social participation (Zhang, 2016). Low-income families can exchange recycling materials for school supplies. Another contribution to environmental stability is promoting the retrofitting of buildings rather than demolition and reconstruction. As a result of this economic stability, Curitiba has the 4$^{th}$ largest GDP in the country while only being the 8th most populous city in Brazil. The city has prioritised non-polluting, high-tech industries, thus helping the commercial and service industries to achieve a 7.1% economic growth rate over 30 years (Zhang, 2016).

The important factor that made a significant difference to Curitiba's sustainability was the emphasis on a strategy of positive change through key urban planning principles, such as maximising quality of life by integrating policies of land use and public transport (Zhang, 2016). City planners also stressed the importance of covering each triple bottom line simultaneously. Another contributor to the success of Curitiba was the use of multiple tools/techniques to maintain strategic impact. Although Curitiba is rapidly improving, there are many residents still living in poverty. Areas of focus should be: (i) improving the capacity of public transportation, (ii) reducing greenhouse emissions, (iii) increasing public participation and (iv) developing the economy to reduce poverty.

### 8.5.3 Implementation strategy of case study 1

The data that was available in the case of Curitiba's urbanisation was well documented. It also included the situation that preceded and led up to developing the city according to sustainable practices. This allows for an initial situation to be used as a baseline to input data into the SUPA DSF.

The urban systems elements that the urbanisation phenomena more prominently affect are: (i) residential, (ii) commercial, (iii) industrial, (iv) transport and (v) socio-economic, has been highlighted in the systematic literature review in Chapter 2, Section 2.6.1.

*Table 8.10: User input conditions relating to urbanisation*

| ***CASE 1: Urbanisation*** | | |
|---|---|---|
| ***Criteria*** | | ***Conditions*** |
| ***Conditions*** | Type of Area | Commercial |
| | Size of Area | City wide |
| | Data intensity | Qualitative |
| | Participation necessity | Public |
| | As-is state | Environmental |
| | To-be state | Economic, Environmental and Social |
| | Cost/Budget | Minimal |
| | Probability of success | Low |

Once the data provided by the Curitiba case study[3], as summarised in the table above, had been inputted, it was evaluated by the SUPA DSF. It compared all the tools and techniques to produce the appropriate tool/technique for assisting sustainable urban planning efforts in Curitiba.

The Trinity of cities sustainability from spatial, logical and time dimensions' (TCS-SLTD) framework delineates the evolution of cities' sustainability in developing countries, and accounts for cities' multi-dimensional natures when evaluating such sustainability (Ding *et al.*, 2015). The model adopts a causal network eDPSIR framework (the enhanced Drivers-Pressures-States-Impacts- Responses) as well as a Multi-Domain Fuzzy Sentiment. Analyzer (MDFSA) approach. The MDFSA is a tool for uniting indicators from several areas in order to uncover hidden inter-relations, and to compare different system-level states (Ding *et al.*, 2015). As is evident from the name, the TCS-SLTD assesses the sustainability of cities by using three concrete, yet linked, dimensions – space, logic and time (Ding *et al.*, 2015). The TCS-SLTD also evaluates the city's compactness with regard to the standards: (i) functional interactions of socio-economic activities occur within city boundaries, (ii) spatial distribution of functions adhere to carrying capacity, and (iii) optimizing urban expansion through rational planning and effective development control (Ding *et al.*, 2015).

The SUPA was utilised by gathering all the necessary information for the user input. Table 8.11 shows the top 3 tools/techniques from the intermediate table when inputting the urbanisation case study. The top 3 tools/techniques were: (i) Trinity of cities sustainability, (ii) Conceptual design matrix for sustainable urban form and (iii) Sustainable urbanisation framework.

*Table 8.11: Top 3 tools/ techniques from urbanisation case intermediate table*

| Tool/ Technique | Type of Area | Size of Area | Data Intensity | Participation necessity | As-is State | To-be State | Cost/ Budget | Probability of Success | Total |
|---|---|---|---|---|---|---|---|---|---|
| Trinity of Cities Sustainability | 1 | 1 | 0 | 1 | -3 | 9 | 1 | 1 | 11 |
| Conceptual design matrix for sustainable urban form | 1 | 1 | 1 | 0 | -2 | 6 | 1 | 1 | 9 |
| Sustainable urbanisation framework | 1 | 1 | 0 | 0 | -3 | 8 | 1 | 1 | 9 |

For further confirmation of the TCS-SLTD found by the SUPA, an assessment was compiled with an AHP in Appendix C.1. This assessment used the initial urban system elements and sustainable development goals defined for each of the three sustainable urban planning challenges in Sections 2.6.1 and 2.6.2.

*Table 8.12: SUPA DSF user output (urbanisation case study)*

| **Tool/Technique: Trinity of Cities' Sustainability from Spatial, Logical and Time Dimensions (TCS-SLTD)** | | |
|---|---|---|
| Criteria | | Conditions |
| 1. Type of Area | | Commercial |
| The TCS-SLTD matches the commercial urban system element. Therefore, in order to implement this effectively, the user can support the commercial sector of the city to become prosperous via developing quality environmental impacts and, furthermore, maintaining high density with local facilities and services. | | |
| 2. Size of Area | | City wide |
| The TCS-SLTD matches the Size of Area. Therefore, in order to implement this effectively, the user can gather the data necessary for the compactness analysis and, furthermore, develop a compact strategy that adheres to the outputs from the TCS-SLTD. | | |
| 3. Participation Necessity | | Public |
| The TCS-SLTD matches the Participation Necessity. Therefore, in order to implement this effectively, the user can gather information regarding the Time Dimension data to be used for the Logical Dimension analysis, and furthermore, understand the needs for improving the social wellbeing and the residents' quality of life. | | |
| 4. As-is State | | Environmental |
| The TCS-SLTD matches the As-is State. Therefore, in order to implement this effectively, the user can capture the data for the positive environmental impacts currently in place. | | |
| 5. To-be State | | Economic, Environmental and Social |
| The TCS-SLTD matches the To-be State. Therefore, in order to implement this effectively, the user can adhere to the TCS-SLTD tool, which should assist with a successful triple bottom line, and furthermore, the outputs can develop strategies toward improving the ecosystem service value (ESV). | | |
| 6. Data Intensity | | Qualitative |
| The TCS-SLTD does not match the Data Intensity. Therefore, in order to implement this effectively, the user can contract a consultant/specialist to assist with the expertise needed data collection, and furthermore, develop systems to improve quantitative methods for future projects. | | |
| 7. Probability of Success | | Low |
| The TCS-SLTD matches the implementation difficulty. Therefore, in order to implement this effectively, the user can contract a consultant/specialist to assist with the expertise needed for the TCS-SLTD. | | |
| 8. Cost/Budget | | Minimal |
| The TCS-SLTD does match with the Cost/Budget. Therefore, to implement this effectively, the user can reduce costs with simple methods of urban planning and reducing the difficulty, and furthermore, always maintain the objective of sustainability. | | |
| *Reiteration indicator: A reminder to execute the SUPA DSF after 12 months after initial use. Using the to-be state of current project as the new user input for reiteration.* | | |
| *Source:* (Ding *et al.*, 2015) | | |

### 8.5.4 Discussion of case study 1 findings

Most of the tools/techniques used for assessing sustainability in cities have multi-dimensional structures, in order to replicate the complex landscape of cities more accurately (Ding *et al.*, 2015). The urbanisation phenomenon is complex in nature and causes the systemic transformation of cities. These changes can be positive; however, in developing countries with limited resources and expertise, such transformation can disrupt the urban system. The TCS-SLTD framework makes recommendations, through multi-dimensional analysis, on how to direct the city of Curitiba toward a more regenerative development path. "*These include revitalization of the urban system, control of urban form through planning, consulting and informing local communities about sustainable development issues, and achieving efficient functioning and harmonious coordination among different departments and municipal authorities*" (Ding *et al.*, 2015, p. 74). A comparison with the implementation of the Curitiba case, which focused on balanced urban planning approaches, such as developing local communities via environmental and socially impactful strategies, is helpful. Both the approach used in Curitiba and the TCS-SLTD focus on the revitalization of urban systems through local communities.

The similarities between the implementation strategy of Curitiba and the SUPA output are evident. It is unclear what outcome the TCS-SLTD would provide in the case of Curitiba. However, the TCS-SLTD is specifically designed for developing countries. Therefore, with enough quantifiable data, which is not always available, the tool/technique recommended by the SUPA DSF could be helpful. But, with reference to the specific Curitiba case, the data availability would be a disadvantage as it was primarily qualitative. Furthermore, this finding should affirm the SUPA's relevancy and practicability when implementing within real-world scenarios.

In evaluating the relevancy of the SUPA DSF, by referring to the applicability in the context of real-world situations, the case study of urbanisation has showcased the suitability of using the SUPA DSF in the case of Curitiba, by providing viable solutions that would improve the sustainability of urban planning in that city. In evaluating the practicability of the SUPA DSF, it refers to the simplicity and degree to which the tool is easy to comprehend. The User Output provided in Table 8.12 reveals how the SUPA DSF recommends an implementation strategy alongside the appropriate tool/technique for the sustainable project.

## 8.6 Case study 2: Urban sprawl

The second case study explored the city of Ankara, Turkey, in terms of its social, environmental and economic scales. Much of this case study was developed for the 2013 issue of the *International Journal of Sustainable Transportation*[4]. This reflects the equivalent aim and research objectives of this research study. The case study thus focused on a city in Turkey that is classified as a middle-income developing country. Furthermore, the case is retrospective in nature due to the extensive assessment and analysis achieved throughout the study. Therefore, the case of Ankara fits the criteria for the case of Urban Sprawl. The aim of looking at this particular case study was to determine whether the SUPA DSF developed in our research would be able to address gaps or advance the strategy that was developed and implemented in the Ankara case study[4].

[4] (Babalik-Sutcliffe, 2013), DOI: 10.1080/15568318.2012.676152

### 8.6.1 Background of case study 2

The aim of this second case study was to compare two development corridors in Ankara in terms of their urban-development patterns, density, and diversity, as well as the transport and traffic outcomes. It focused on policy analysis, "*concentrating on both the results of, and the degree of accomplishment in carrying a planning policy that seeks to strengthen urban development along corridors together with a mixed land-use strategy*" (Babalik-Sutcliffe, 2013, p. 419). Ankara is the capital city of Turkey and is home to 3.5 million people in a historically high-density development and a rather compact form. Most businesses, services and amenities are located in the city centre, and this began to be a problem in the 1970s in the face of rapid growth, particularly at the fringes of the city, resulting in continuous urban sprawl (Babalik-Sutcliffe, 2013). See Figure 8.4 for Turkey's population growth of licenced vehicle drivers since 1950.

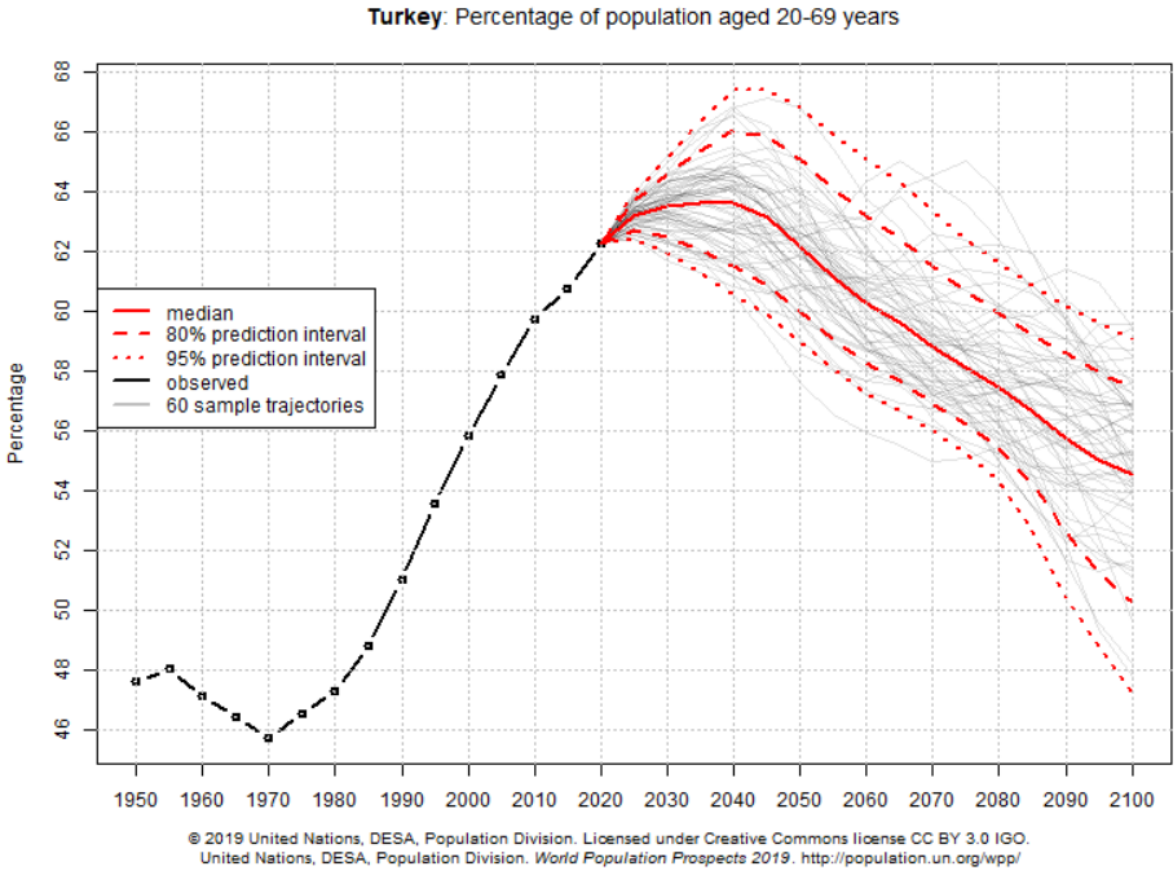


*Figure 8.4: Percentage of population of licenced vehicle drivers in Turkey. Source: (United Nations DESA, 2019)*

The above figure resembles the percentage of population increase from 1970 to the present. The age group of 20-69 years is the majority of able and legal drivers in the country. Therefore, the increase from 46% to 62% represents a large increase in the number of commuters who need to be accommodated on the roads. Moreover, urban planners would need to continuously increase the capacity of the roads or upgrade the public transport system.

The compact city model has been emphasised in debates, which have argued that urban intensification, high-density development, and mixed-use development tactics not only help to prevent urban sprawl, but also benefit travel behaviour by launching the housing, workplaces and amenities dynamic (Babalik-Sutcliffe, 2013). "*Urban planners need to increase the density of persons per km*$^2$*, at which automobile* *dependence can be reduced and public transport more easily promoted*" (Babalik-Sutcliffe, 2013, p. 422). This tactic signifies the recommended ordering of planning from the compact form into corridor development. However, this tactic placed significant pressure on public transport. If automobile dependence persists, it would cause many more problems given the challenges of increasing urban sprawl. Studies have shown that urban sprawl is reduced with compact city planning and mixed-use strategies (Babalik-Sutcliffe, 2013). However, the management of such strategies is hard to maintain with higher population. Moreover, studies are clear on the impact of decreased quality of life with regard to traffic congestion (Babalik-Sutcliffe, 2013). It is also problematic when residents need to live outside of town in order to be able to afford the accommodation, but they need to work in town or to find work in town. This dynamic of traveling long distances between home and work is unhealthy for people, especially if they spend more than two hours in traffic every day. A problem relating to the compactness dynamic, however, is objections from residents regarding building density and additional infrastructure, which they regard as unacceptable (Babalik-Sutcliffe, 2013). Therefore, finding consensus of public participation is another challenge when it comes to dealing with urban sprawl. The next best alternative besides the compact form is corridor development (Babalik-Sutcliffe, 2013). This builds up the surrounding land along a popular road with a mixed-use strategy to increase the capacity and quality of public transport. This type of approach is the main technique used within this case study and will be further discussed in Section 8.6.4.

A common factor of urban sprawl is the amplified private car usage that relates to traffic congestion and air pollution (Babalik-Sutcliffe, 2013). Altering travel behaviour is a possible way of curbing some of the problems caused by urban sprawl. If cities emphasise public transport and nonmotorized journeys, then decreased distances between socioeconomic activities are a must, which is more likely with higher densities of urban areas (Babalik-Sutcliffe, 2013). A plan that prioritises the implementation of mixed land use strategies should be encouraged rather than restricting urban growth.

Cities around the world have experienced varying success in limiting urban expansion, and experts point out that creating a greenbelt, on many occasions, actually instigates leapfrog development (Horn, 2015). Leapfrog developments provides land reserves for upcoming freeways, where people living on the other side of the greenbelt need to commute even longer distances to the city. The best course of action is to "*manage urban sprawl by prioritizing intensification and mixed-use development, providing transportation alternatives and housing choices, while still promoting targeted economic growth*" (Horn, 2015, p. 136). Many studies have witnessed the detrimental effects of trying to solve urban sprawl via urban containment. Planning committees had the best intentions to protect the environment. However, they were not prepared for rapid population growth, which led to cheap residential development away from the city. This forced commuters to increase their travel distances, which produced more harmful gas emissions, which were probably not equivalent to the land saved by means of the urban containment strategy. Significant motives given for the disapproval to urban sprawl are "*social inequalities, the consumption of agricultural land, traffic congestion and social negatives of suburban living*" (Horn, 2015, p. 137). Sustainable urban forms bring diversity to development and allow homes and workplaces to be in closer proximity, therefore reducing the length of motorised rides, and occasionally removing the need for driving by turning walking into a feasible substitute (Babalik-Sutcliffe, 2013). These sustainable urban planning ideas are harder to implement than an urban containment boundary. However, with enough planning and public participation, the sustainable practices within the urban system have much higher chance of success for the long-term sustainability of the city and its inhabitants. Understanding and navigating the complex urban system within its unique context is the first step to creating sustainable cities. Sustainability is a difficult concept to comprehend and define because urban forms are all contextual and need to be implemented specifically and uniquely for every new project. There is no blueprint that urban planners can follow that had been implemented in another city project.

### 8.6.2 Reality of case study 2

Since the 1970s, "*planning studies in Ankara have aimed at transforming the compact and problematic urban form into a controlled decentralization along two main corridors of development*" (Babalik-Sutcliffe, 2013, p. 418). So, this case study investigates the dynamic of the compact urban form and the implementation of corridor development to alleviate the urban sprawl situation in Ankara. The study is mostly a policy analysis of planning strategies that have come under strain from urban sprawl. The data collected was from travel and household surveys carried out by local governments, and utilising the 2023 master plan for Ankara and a database of the city population, density and employment (Babalik-Sutcliffe, 2013). The second part of the analysis made use of the traffic accumulated within those corridors (Babalik-Sutcliffe, 2013). This allowed for a comparative assessment with the plan versus the reality of the corridors.

Traffic levels in both corridors that were under development in Ankara increased over the years, which is obvious, given urban sprawl and population growth (Babalik-Sutcliffe, 2013). Figure 8.4 illustrates the dramatic increase of the driving population in Turkey. The western corridor, which featured a higher density and diversity of development, created a significant decrease in car usage when compared to the city average (Babalik-Sutcliffe, 2013). In comparison, the south-western corridor has a much higher private automobile usage rate, providing evidence of the negative effects of car-dependent, lower-density and higher-income residential development (Babalik-Sutcliffe, 2013). Therefore, an important consideration would be to increase the number of buildings in the south-western corridor that are non-residential. This would increase the density of the south-western corridor and consequently reduce the private car traffic in the area. This would have to include the higher-income bracket of employment, which is predominantly focused in business parks or high-rise buildings. However, this would also undermine the market attraction for low-density neighbourhoods for higher-income individuals. Low densities within cities need to adapt to change regarding sustainable forms that contribute to the longevity of cities. Therefore, as was the aim of the case in question, the goal would be to increase the density of inner cities, and then implement transportation capacity measures by incentivising the public transport. Urban sprawl is a wasteful form of development as household spending rises due to the increased length of trips; it furthermore consumes agricultural land which increases the costs of agriculture, due to low-density, spread-out development (Batty, Besussi and Chin, 2003). Low-density, car-based urban development has more negative effects than higher density development for traffic congestion (Batty, Besussi and Chin, 2003).

Residential development alongside urban sprawl challenges must be holistic and strategic. "*The government-led housing projects and industrial development along the western corridor resulted in a residential area profile that was middle-income and more transit-dependent*" (Babalik-Sutcliffe, 2013, p 425). Therefore, the more reasonable approach would be to improve the business and public transport sector for this passage. Ensuring a mixed-use strategy is a very useful method for balanced sustainable urban forms. In the case of the southern corridor, "*Market-led residential growth, state office development, and universities which attracted higher-income residents with high car-ownership levels, enabling and promoting a more car-oriented urban pattern*" (Babalik-Sutcliffe, 2013, p. 426) were implemented. This interesting contrast between the two corridors makes the study a stimulating investigation because context is vital to any sustainable project. The corridors are not located far from one another spatially, but the socioeconomic and density differences change the method of approach. Unfortunately, no provision had been made for connecting the pre-existing metro station to the corridors when the new corridors were being planned, or when new sites for the metro stations were being selected (Babalik-Sutcliffe, 2013). As a result, none of the metro stations have been positioned for easy or direct access to and from the new developments. This planning failure was interesting since the metro was currently operating at a low capacity and needed better utilisation. "*The developers rather chose to focus on road accessibility when designing both the residential and non-residential areas*" (Babalik-Sutcliffe, 2013, p. 426). This choice in favour of road-based public-transport systems will need to be investigated in future studies to assess the effectiveness of the altered system.

It is apparent that such development styles can help to decrease the need to travel to the CBD (Babalik-Sutcliffe, 2013). It is also understood that these approaches need support from transport policies that promoted and inspired public-transport use, while restricting parking and car usage in the city centre (Babalik-Sutcliffe, 2013). Because of the decision to implement road-based public transport rather than connecting the metro to the corridors. To summarise, the urban forms along the two development corridors in Ankara display stark differences. This case study has thus verified that a mixed-use strategy can be a powerful factor in changing home-work patterns and reducing the need to travel to the city centre.

### 8.6.3 Implementation strategy of case study 2

The data that was available in the case of Ankara's urban sprawl was well documented and included the situation that led up to the development of the city in accordance with sustainable practices. This allows for an initial situation to be used as a baseline to input data into the decision support framework.

The urban systems elements that the urban sprawl phenomena more prominently affect are: (i) residential, (ii) business, (iii) community, (iv) biophysical, (v) infrastructure, (vi) transport and (vii) socio-economic, has been highlighted in the systematic literature review in Chapter 2, Section 2.6.3.

*Table 8.13: Urban sprawl user input conditions*

| ***CASE 2: Urban Sprawl*** | | |
|---|---|---|
| ***Criteria*** | | ***Conditions*** |
| ***Conditions*** | Type of Area | Transport network |
| | Size of Area | City Wide |
| | Data intensity | Quantitative |
| | Participation necessity | Public |
| | As-is state | Economic |
| | To-be state | Economic, Environmental and Social |
| | Cost/Budget | Minimal |
| | Probability of success | Medium |

After the data provided by the Ankara case study[4], as seen in the table above, had been inputted into the SUPA DSF, it evaluated the information. It compared all the tools and techniques to generate the appropriate tool/technique to assist sustainable urban planning efforts for the Ankara case[4]. Neotraditional development was the highest ranked technique; this entails transit supportive development techniques like Transit orientated development (TOD). This falls into a very similar category as that which had been implemented in the Ankara case[4].

The SUPA DSF gathered all the necessary information for the user input. Table 8.14 shows the top 3 tools or techniques from the intermediate table when inputting the Urban Sprawl Case study. The top 3 tools or techniques were: (i) Neotraditional and urban containment, (ii) New urban agenda and (iii) Eco-effective architecture.

*Table 8.14: Top 3 tools/ techniques from urban sprawl case intermediate table*

| Tool/ Technique | Type of Area | Size of Area | Data Intensity | Participation necessity | As-is State | To-be State | Cost/ Budget | Probability of Success | Total |
|---|---|---|---|---|---|---|---|---|---|
| Neotraditional and Urban Containment | 1 | 1 | 1 | 1 | -2 | 9 | 1 | 1 | 13 |
| New Urban Agenda | 1 | 1 | 1 | 1 | -2 | 10 | 1 | 0 | 13 |
| Eco-effective architecture | 1 | 0 | 1 | 0 | -3 | 8 | 1 | 1 | 9 |

For further confirmation of the ND & UC found by the SUPA DSF, an assessment was compiled with an AHP in Appendix C.2. This assessment used the initial urban system elements and sustainable development goals defined for each of the three sustainable urban planning challenges in Sections 2.6.3 and 2.6.4.

### 8.6.4 Discussion of case study 2 findings

Usually, in the case of urban sprawl, the best course of action would be to target the urban fringes and restrict growth. Neotraditional development methods seek to connect all available resources within the city, by emphasising all modes of public transport (bus, metro, train, bicycle, etc.) so that these become easier to access. By incorporating these ideals, the urban setting can then be shaped to reduce the need for private car ownership. This ideal is not always fool proof, however, as is indicative of the medium difficulty of implementation of this method.

*Table 8.15: SUPA DSF user output (urban sprawl case study)*

| **Tool/Technique: Neotraditional Development and Urban Containment (ND & UC)** | | |
|---|---|---|
| Criteria | | Conditions |
| 1. Type of Area | | Transport Network |
| The ND & UC matches the Transport Network urban system element. Therefore, in order to implement this effectively, the user can focus on high densities, mixed uses, and sustainable transport methods, such as incentivising public transport, and, furthermore, associate the sustainable costs of expansion to minimise land consumption and mobility generation. | | |
| 2. Size of Area | | City wide |
| The ND & UC matches the Size of Area. Therefore, in order to implement this effectively, the user can develop an objective to achieve sustainable outcomes for the city and, furthermore, ensure that automobile dependency is limited. | | |
| 3. Participation Necessity | | Public |
| The ND & UC matches the Participation Necessity. Therefore, in order to implement this effectively, the user can develop plans that incorporate public participation. Traffic problems are predominantly behavioural and urban planning has the capability to change patterns through effective planning to achieve more sustainable transit use. | | |
| 4. As-is State | | Economic |
| The ND & UC matches the As-is state. Therefore, in order to implement this effectively, the user can capture the data for the positive economic impacts currently in place. | | |
| 5. To-be State | | Economic, Environmental and Social |
| The ND & UC matches the To-be state. Therefore, in order to implement this effectively, the user can follow all the methods used via ND & UC to achieve greater city sustainability and, furthermore, put in place strict guidelines to adhere to ND & UC principles and reduce developer authority. | | |
| 6. Data Intensity | | Quantitative |
| The ND & UC matches the Data Intensity. Therefore, in order to implement this effectively, the user can ensure the data is captured proficiently and, furthermore, ensure that plans are conducted with prominence to data-driven results. | | |
| 7. Probability of Success | | Medium |
| The ND & UC matches the implementation difficulty. Therefore, in order to implement this effectively, the user can source experts in ND & UC to increase the success of project and, furthermore, reduce the risk by using data-driven decisions. | | |
| 8. Cost/Budget | | Minimal |
| The ND & UC matches the Cost/Budget. Therefore, in order to implement this effectively, the user can reduce costs with simple methods of urban planning and reducing difficulty, and furthermore, always maintaining the objective of sustainability. | | |
| *Reiteration indicator: A reminder to execute the SUPA DSF after 12 months after initial use. Using the to-be state of current project as the new user input for reiteration.* | | |
| *Source: (Camagni, Gibelli and Rigamonti, 2002; Horn, 2015; Wicaksono, 2017)* | | |

Another approach the Ankara case[4] developed was that of mixed land use. This establishes the possibility of decreasing the distance between work and home. The SUPA DSF's decision to suggest the Neotraditional development technique would target this work-home dynamic by increasing the number of different transportation modes available to citizens in transit. Bridging public transportation with each new urban development should be obligatory, as this increases the return on investment for the project, as this transit resource already contains enough capacity. This is evident from the fact that Ankara's metro was only functioning at 30% capacity (Babalik-Sutcliffe, 2013). Furthermore, it was not connected to the corridors that were developed, which effectively forced people to use private car transport. This is the reason for the increased traffic that was evident along both corridors. This was a missed opportunity, due to the expected increase in socio-economic activity, which had been the intention. It has resulted in a transport system that favours car usage and is not metro-friendly (Babalik-Sutcliffe, 2013). Transit orientated design (TOD) would increase the utilisation of the metro by incentivising the transport option. This can be accomplished via economic means, such as discounts on products sold in the city if a metro passenger was the purchaser. Or, the inclusion of the option of a multi-story car park on the outskirts of the city for outer city passengers who can access the metro from there. Another option that has proved successful in London is taxing different vehicle types when entering the centre of London. This decreases gas emissions and reduces traffic, and the passenger tax can contribute to safer roads. These alternative options reveal the number of strategies that are available but that may not be suitable for other contexts.

The similarities between the Ankara case[4] implementation strategy and the SUPA DSF output are evident. When facing the challenge of urban sprawl, Ankara did not implement the usual urban containment approach. Instead, city planners targeted high activity zones and implemented mixed land use to achieve sustainable outcomes with regard to each triple bottom line. The SUPA DSF, in contrast, targeted the transportation support development by recommending the Neotraditional technique. This finding should affirm the relevancy and practicability of the SUPA DSF when being implemented in real-world scenarios.

This section has evaluating the relevancy of the SUPA DSF by looking at a real-world context. The urban sprawl study in the case of Ankara has demonstrated the suitability of using the SUPA DSF in order to identify viable solutions that could improve the sustainability of the city. The practicability of the SUPA DSF, referring to the simplicity and degree to which the tool is innate to comprehend, has been evaluated. The user output provided in Table 8.15 reveals how the SUPA DSF recommends an implementation strategy alongside the appropriate tool/technique for the sustainable project.

## 8.7 Case study 3: Population growth

In the third case study, the social, environmental, and economic scales in the city of Singapore were explored. Much of this case study had been developed for the 2016 issue of the *Journal of Urban Planning and Development*[5]. This reflects the equivalent aim and research objectives of our own research study. The case study was done in what is currently classified as a developed country. However, this case demonstrates the transformation of Singapore from a developing country only a few decades prior. Furthermore, the case is retrospective in nature due to the extensive assessment and

[5] (Mohareb, Derrible and Peiravian, 2016), DOI: 10.1061/(ASCE)UP.1943-5444.0000287

analysis achieved throughout the study. Therefore, the case of Singapore fits the criteria for the case of population growth.

### 8.7.1 Background of case study

In the last 50 years, Singapore has transformed from a developing country into a developed one while tripling its population and increasing the GDP by a factor of 90 in real-world terms (Mohareb, Derrible and Peiravian, 2016). Singapore's planning authority, the Urban Redevelopment Authority, established a distinct zoning code for commercial and residential developments. Much of Singapore's public and private housing is high density, exhibited in multi-unit towers. Singapore is known for implementing original transit policies, such as the moderately high vehicle possession taxes (Mohareb, Derrible and Peiravian, 2016). This is similar to London, which implemented taxes on central city commuters in terms of the type of vehicle used. For instances, if trucks were entering central London, they would be taxed mostly due to their carbon footprint. Conversely, eco-friendly/electric cars would be taxed almost zero due to their low carbon footprint. As mentioned before, this reduces traffic, decreases gas emissions and allows for the taxes to go toward improving urban transit. "*The apparent success of Singapore's approach resides in both infrastructure investment (i.e., ample public-transit options) and strong travel-demand-management policies*" (Mohareb, Derrible and Peiravian, 2016, p. 5). However, this is coupled with the mixture of building ages, which is impractical. The infrastructure difference throughout the city is most likely due to the rapid population growth since Singapore gained independence from Malaysia in 1960. Since there was already a base of buildings before independence, Singapore needed an updated development plan to keep up with the growing population. The impracticality of the situation lies in the existence of historical buildings that do not age well in a rapidly growing country. See Figure 8.5 for the population growth of Singapore since 1950.

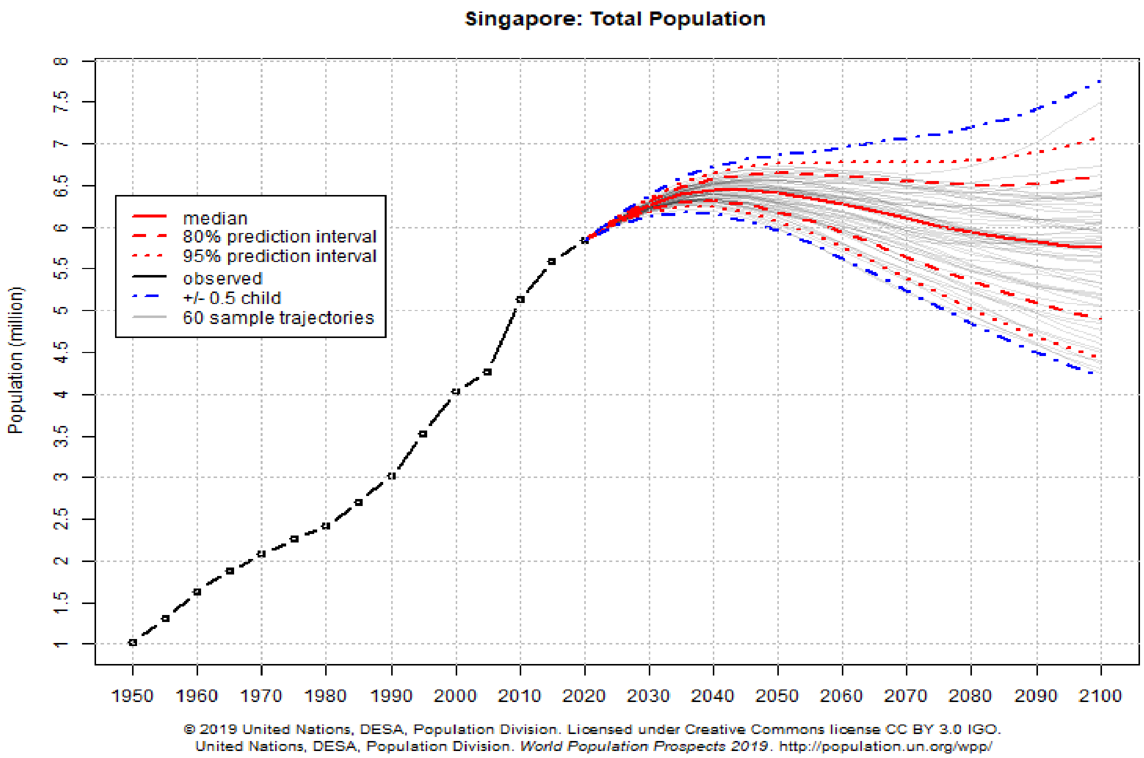


*Figure 8.5: Singapore total population since 1950. Source: (United Nations DESA, 2019)*

With its rapid population growth on a small island, Singapore has been able to curb traffic congestion by using a bold transit-oriented development strategy. "Countless cities from emerging countries are rapidly expanding and are faced with the challenge of developing in a way that enhances economic prosperity while keeping adverse environmental and social impacts low" (Mohareb, Derrible and Peiravian, 2016). This is a difficult combination to attain. Balanced sustainability is good for the longevity of a city/country.

The case of Singapore is somewhat unique because, as an island city-state, its growth is geographically constrained, and its population is mostly concentrated in high rises. The impact of population density on key metrics of sustainability (energy use, GHG emissions) is well known. Singapore has an unusual metric when it comes to motor vehicle ownership and GDP/capita; they have one of the lowest numbers of cars per GDP/capita (Mohareb, Derrible and Peiravian, 2016). This means that, with the high density of the population and positive GDP growth, Singapore has the least number of motor vehicles per 1000 people. Therefore, the economy of the city can grow with a high density of people without the common characteristic of high levels of car ownership that is common in other developed countries. The motor vehicle ownership statistic is targeted specifically at developed countries. However, the case of Singapore clearly proves that it is possible to transform a developing country into a developed one. By adapting sustainable urban planning practices, cities reduce GHG emission, reduce transport expenses, improve transport efficiency, and more effectively utilise land. "*Approaches stemmed from the view that cities are self-organizing complex systems and should be encouraged to develop according to microscale social and market forces*" (Mohareb, Derrible and Peiravian, 2016, p. 1). It is worth repeating that public participation is vital to the success of sustainable urban planning practices. It is recognised that cities often have problems changing to low-carbon technologies due to the unsatisfactory alleviation of GHG emission targets (Mohareb, Derrible and Peiravian, 2016). An optimal approach would be to transfer to more renewable technologies, but this first requires the correct resources and expertise, and therefore, shifting behaviour through urban planning methods. In this case, the study of urban sustainability is part of the fundamental topic of low-carbon urban infrastructure (Mohareb, Derrible and Peiravian, 2016). Now, if we compare Singapore to the rest of the world's developing countries' population in Figure 8.6, then the graphic would look the same and prove how impressive Singapore's effort is to improve into a developed country. The evaluation of how Singapore has been able to graduate to a developed country will be discussed in Sections 8.7.2 and 8.7.2.3.

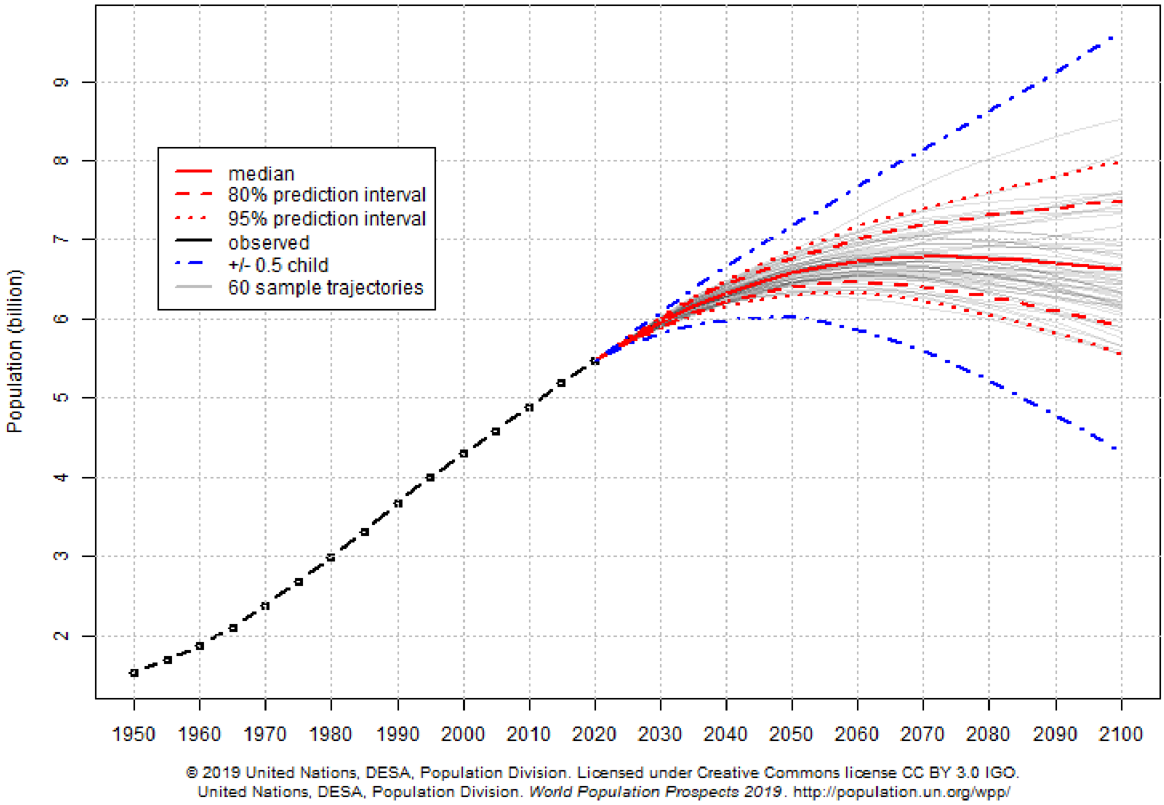


*Figure 8.6: Less developed regions, excluding least developed countries (total population). Source: (United Nations DESA, 2019)*

Figure 8.6 illustrates the total population of the less developed regions (of which China and India contribute over 2.7 billion), excluding 47 countries, according to the United Nations. These countries include 33 countries from Africa, 9 countries from Asia, 4 countries from Oceania and Haiti.

The classification of the least developed countries is (United Nations):

i. Income: thresholds are $1025, which is set at the three-year average of gross national income (GMI) per capita.
ii. Human assets: calculated using five indicators grouped into health and education sub-indices.
iii. Economic vulnerability: measured using structural vulnerability to economic and environmental shocks.

The population growth of underdeveloped countries has been increasingly constantly over the last 70 years. Of the 5.5 billion people as of 2020 in Figure 8.6, 2.8 billion people from India and China are excluded. India and China have much research focusing on sustainable urban planning. According to that research, the other 2.8 billion inhabitants of developing countries have an opportunity to improve their urban sustainability. They need to understand that tool/techniques implemented in developed countries will not work for the developing country context. Therefore, a good starting point is to gather technology and data to understand their own context. This approach is most likely the reason for Singapore's success in implementing a context-specific sustainable urban form.

### 8.7.2 Reality of case study 3

Public opinions and ideals can be influenced by urban planning. "*As cities grow, their infrastructure stocks develop in tandem (or at least attempt to), influenced by changing planning and development trends*" (Mohareb, Derrible and Peiravian, 2016, p. 8). The case of Singapore is particularly relevant when considering historical, climatic, and landscape factors. Singapore, which is an island with a tropical climate and physically constrained, has seen more recent infrastructural growth and contains more high-rise buildings than many other developed countries. Aspects such as periods of development, urban form, economic circumstances, policy tactics, physical settings, etc. were the main elements assessed in the case study of Singapore. Strategies to reduce the carbon emissions and carbon footprint must be adapted to their individual contexts (Mohareb, Derrible and Peiravian, 2016). With respect to climate, research suggests that cities experiencing more extreme conditions may have to contend with a stronger tendency toward the use of passenger vehicles over public/private transportation (Mohareb, Derrible and Peiravian, 2016). This dynamic also increases the difficulty of implementing renewable technologies in tandem with reducing adverse climate conditions and transportation. However, Singapore's policies of restricting cars prove an effective approach to overcome this, and low transportation-related emissions can result in improved sustainability with regard to all three of the triple bottom line elements.

Growth density in the spirit of sustainable urban planning tools and techniques can translate into reduction of GHG emissions in cities (Mohareb, Derrible and Peiravian, 2016). In other words, when there is urban population growth in a city, if there is a focus on decreasing GHG emissions via planning and management, then the sustainability of the city will inevitably increase. Singapore has developed fairly recently and has a relatively low road density throughout its entire area. High road density is simply not needed (and neither are other passenger vehicle-related infrastructures) (Mohareb, Derrible and Peiravian, 2016). Singapore also has housing complexes that are integrated with commercial space. Such a combination of mixed-use land use and transit-oriented development has been the true reason for Singapore's successful transformation in the last few decades.

#### *8.7.2.2 Implementation strategy*

The data that was available in the case of Singapore's population growth was well documented and included the situation that led up to developing the city in accordance with sustainable practices. This allows for an initial situation to be used as a baseline to input data into the SUPA DSF.

The urban system elements that the population growth phenomena more prominently affect are: Residential, Community, Biophysical, Infrastructure, Socio-economic, as has been highlighted in the systematic literature review in Chapter 2, Section 2.6.5.

*Table 8.16: Population growth user input conditions*

| *CASE 3: Population Growth* | | |
|---|---|---|
| | ***Criteria*** | ***Conditions*** |
| ***Conditions*** | Type of Area | Residential |
| | Size of Area | City Wide |
| | Data intensity | Quantitative |
| | Participation necessity | Governmental |
| | As-is state | Environmental |
| | To-be state | Environmental and Economic |
| | Cost/Budget | Minimal |
| | Probability of success | Medium |

After the data provided by the Singapore case study, as seen in the table above, was inputted into the SUPA DSF, it evaluated the information. It compared all the tools and techniques to identify the appropriate tool/technique to assist sustainable urban planning efforts in the case of Singapore.

The New urban agenda aims to harness the potential of cities and human settlements to help eradicate poverty in all its forms and dimensions, reduce inequalities, promote inclusive growth, and achieve sustainable development (Roggema, 2016). One of the ideologies defined is to "*transform the way we plan, develop, govern and manage cities and human settlements, recognizing sustainable urban development as an important device to attain success for all and sustain balanced development*" (Roggema, 2016, p. 2). Regarding population densities and compact design, the new urban agenda "*encourage[s] spatial development strategies, prioritizing urban renewal by planning for the provision of accessible and well-connected infrastructure and services*" (United Nations (Habitat III), 2017, p. 15). This reveals how broad and holistic the New urban agenda is with regard to sustainable urban planning.

The new urban agenda furthermore calls for food systems planning, which is a vital addition of as part of future urban planning and urban governance, considering population growth. This theoretically provides an incentive for spatial planning to focus on urban food systems. However, "*the portrayal of the food system within the New urban agenda disregards the extensive and swift conversion of developing countries' urban food systems*" (Battersby, 2017, p. 418).

Another important factor of the new urban agenda is effective implementation. This recognises that policies should be enabled across the country so that participatory planning includes sharing the best tools/techniques throughout all levels of government (United Nations (Habitat III), 2017). This leads to the next point of urban governance, namely, establishing a supportive structure based on the promotion of principles of equality, non-discrimination, age, and gender. Civil society and government need to operate on well-resourced mechanisms and platforms to achieve such a structure (United Nations (Habitat III), 2017).

Planning and managing urban spatial development via flexible building plans that adjust to socioeconomic conditions (United Nations (Habitat III), 2017) is important. For sustainable practices to be successful, they need to be adaptable and flexible to the needs of the inhabitants. That is a main feature of the New Urban Agenda's approach to balanced sustainability. With regard to disaster mitigation, local populations need to secure their shelter and economic needs (United Nations (Habitat III), 2017). In uncommon situations, the new urban agenda seems to ensure that plans are in place to reduce impacts of climate change and environmental disasters to vulnerable people. According to a brief assessment to the procedures followed by the new urban agenda, it prioritises social improvements. Population growth contributes significantly to social dilemmas within cities (United Nations (Habitat III), 2017). Therefore, it is possible to say that the SUPA DSF chose a useful and effective technique to combat the challenges associated with population growth in Singapore.

The SUPA DSF was utilised by gathering all the necessary information for the user input. Table 8.17 shows the top 3 tools or techniques from the intermediate table when inputting the population growth case study. The top 3 tools or techniques were: (i) New urban agenda, (ii) Z-Farming and (iii) Eco-effective architecture.

*Table 8.17: Top 3 tools/ techniques from population growth case intermediate table*

| Tool/ Technique | Type of Area | Size of Area | Data Intensity | Participation necessity | As-is State | To-be State | Cost/ Budget | Probability of Success | Total |
|---|---|---|---|---|---|---|---|---|---|
| New urban agenda | 1 | 1 | 1 | 1 | -3 | 7 | 1 | 0 | 9 |
| Z-farming | 1 | 0 | 1 | 0 | -4 | 8 | 1 | 1 | 8 |
| Eco-effective architecture | 1 | 0 | 1 | 1 | -3 | 6 | 1 | 1 | 7 |

For further confirmation of the NUA found by the SUPA DSF, an assessment was compiled with an AHP in Appendix C.3. This assessment used the initial urban system elements and sustainable development goals defined for each of the three sustainable urban planning challenges identified in Sections 2.6.5 and 2.6.6.

#### *8.7.2.3 Discussion of case study 3 findings*

The urban planning challenge of population growth can cause social disruption if urban planning is implemented poorly (United Nations (Habitat III), 2017). This challenge is thus an important one for developing countries around the world, as seen in Figure 8.6. The world's population has been increasing for the last 70 years. Researchers can only assume that this steady increase will come to a plateau at some stage, because this level of growth is unsustainable for the planet. Developing cities need to manage this growth within their boundaries to ensure that it does not create other urban planning challenges. Singapore is an example of a developing country with high population growth (Figure 8.5) and small land mass, that has graduated to a developed county over only a few decades.

*Table 8.18: SUPA DSF user output (population growth case study)*

| **Tool/Technique: New Urban Agenda (NUA)** | | |
|---|---|---|
| Criteria | | Conditions |
| 9. Type of Area | | Residential |
| The NUA matches the Residential urban system element. Therefore, in order to implement this effectively, the user can focus on housing that has access to basic human needs and services and, furthermore, on the fact that the residential areas need to access affordable and reliable sustainable renewable energy sources. | | |
| 10. Size of Area | | City Wide |
| The NUA matches the Size of Area. Therefore, in order to implement this effectively, the user can encourage cooperation among urban areas and promote urban-rural partnerships for performing services locally and regionally. | | |
| 11. Participation Necessity | | Governmental |
| The NUA matches the Participation Necessity. Therefore, in order to implement this effectively, the user can support the policies and legislation to gain greater transparency and develop sustainably and, furthermore, through cooperation, to meet all relevant stakeholder needs. | | |
| 12. As-is State | | Environmental |
| The NUA matches the As-is State. Therefore, in order to implement this effectively, the user can capture the data for the positive environmental impacts currently in place. | | |
| 13. To-be State | | Environmental and Economic |
| The NUA matches the To-be State. Therefore, in order to implement this effectively, the user can prioritise infrastructure design to drive cost and resource reduction, and furthermore, encourage urban-rural interactions to maximise local productivity. | | |
| 14. Data Intensity | | Quantitative |
| The NUA matches the Data Intensity. Therefore, in order to implement this effectively, the user can ensure the data is captured proficiently and furthermore, ensure plans are conducted with prominence to data-driven results. | | |
| 15. Probability of Success | | Medium |
| The NUA does not match the implementation difficulty. Therefore, in order to implement this effectively, the user can source experts in NUA to increase the likelihood of success of the project, and furthermore, to reduce risk with data-driven decisions. | | |
| 16. Cost/Budget | | Minimal |
| The NUA matches the Cost/Budget. Therefore, in order to implement this effectively, the user can interact with governmental broad-based and well-resourced permanent mechanisms that are open to all to reduce costs, and furthermore, implement anti-corruption measures that promote financial security and integrity. | | |
| *Reiteration indicator: A reminder to execute the SUPA DSF after 12 months after initial use. Using the to-be state of current project as the new user input for reiteration.* | | |
| *Source:* (United Nations (Habitat III), 2017) | | |

The SUPA DSF calculated that the New urban agenda would be the optimal option to combat the challenges posed by population growth in Singapore. The discussion was based on providing the food system, social equality, and housing development for a growing nation. These points were proven important in the background of the Singapore case in Section 8.7.1. The New urban agenda, which is a balanced holistic approach, covers all these points and more. This is strongly related to the sustainable development goals (SDG). The premise was to be a blueprint to fit onto any context. However, as previously discussed, this is very rarely the case, especially with developing countries.

The differences in approach between that used by Singapore and that recommended by the SUPA DSF are stark. Singapore implemented aggressive transport policies that changed the social behaviour of all the inhabitants, forcing them to adhere to the resources available. In contrast, the New Urban Agenda focuses on the socio-economic impacts of a developing city under strain from population growth by focusing on developing social inclusion and ending poverty (United Nations (Habitat III), 2017). This pledge is part of the SDGs and amplifies its importance when dealing with the challenges of population growth in developing countries. The New urban agenda recognises the urban form and infrastructure and the major contributors toward inhabitant behaviour (United Nations (Habitat III), 2017). Therefore, in the case of Singapore's compact urban form, city planners knew they needed to alter travel behaviours by promoting different schemes that contributed to a successful and sustainable city. It is unclear what impact the New urban agenda would have had on Singapore. But, with the brief description of what it entails, it seems it would have had the positive intention of curbing the negative effects of population growth.

This third case study has been used to evaluate the relevancy of the SUPA DSF, by referring to its applicability in the context of real-world situations. The case study focusing on population growth has showcased the suitability of using the SUPA DSF, as it suggested viable solutions that would improve the sustainability of Singapore and its urban planning approach. These sections have also evaluated the practicability of the SUPA DSF, by referring to the simplicity and degree to which the tool is easy and straightforward to comprehend. The user output provided in Table 8.18 reveals how the SUPA DSF recommends an implementation strategy alongside the appropriate tool/technique for the sustainable project.

## 8.8 Concluding remarks concerning the SUPA DSF

Based on the verification process that was followed with the SMEs and the validation process that evaluated the relevancy and practicability of the SUPA, it can be reaffirmed that the SUPA is indeed an effective supporting framework for urban planning practices in developing countries. Furthermore, the SUPA was aimed at creating a holistic approach of contributing toward sustainable outcomes from urban planning. The SME group consisted of researchers in similar fields and urban planning professionals, and the interviews with these SMEs confirmed that the SUPA is a sophisticated framework that does not require a high level of experience or knowledge to operate. However, to use the framework optimally, experts should be contracted to increase the projects' prospective quality and success. Lastly, the SME interviews indicated that the SUPA could also be useful for educational purposes and for training of urban planners.

## 8.9 Conclusion: Chapter 8

The epistemology of pragmatism places importance on understanding the relevance and practicality of the research (Saunders, Lewis and Thornhill, 2009). Therefore, the three case studies discussed above were needed to validate the relevancy of the SUPA DSF in several real-world situations. In this chapter, the SUPA was verified by the SMEs, while the validation process regarding the relevancy and practicability of the DSF was reaffirmed by means of the case studies, by confirming that the SUPA is indeed a supporting framework for urban planning practices of developing countries. A two-step process was conducted and discussed in this chapter. Firstly, semi-structured interviews were conducted with SMEs in the field of urban planning research and related professions. Secondly, three retrospective case studies illustrated the operation of the framework and determined the relevancy and practicability of the SUPA with respect to real-world situations. These validation processes reaffirmed the contributions of the SUPA to the field of sustainable urban planning. The stages of the framework were supported by a large body of literature to support knowledge, which is available for use regarding the recent SLR performed, with the stages that are new to the body of knowledge being verified through the interviews. No critical elements were highlighted that might result in the framework failing in its stated objective.

Chapter 9 focuses on the conclusion and recommendations of the research. Addressing: (i) the overview, (ii) contributions, (iii) research objectives, (iv) limitations and (v) future work.

# Chapter 9: Conclusion and recommendations

In this chapter, the final points are made for the research and its contributions to the sustainable urban planning industry. Also, the research objectives covered throughout and scope for the possible future work of relatable research.

## 9.1 Overview of the research

In this research inquiry, a decision support framework, the Sustainable Urban Planning Assistant (SUPA), was developed. Facilitating urban planners with tools and techniques that offer the appropriate approach to achieving a balance triple bottom line for sustainable projects in developing countries.

To develop the SUPA DSF with a structed method, a system engineering approach was implemented. This comprehensive, iterative problem solving technique begins by identifying an environmental requirement and analytically altering it into a solution (US Department of Defense Systems Management College, 2001). In this thesis, four phases were utilised: (i) input identification, (ii) requirements analysis, (iii) functional analysis, and (iv) design synthesis.

In Chapter 1, the research was introduced. Discussing the background, the research aim and objectives, the scope, research methodology and approach.

In Chapter 2, the first phase of the systems engineering approach. Input identification entailing the identifying and contextualising the different factors that had to be considered. A systematic literature review was conducted to collect all the recent sustainable urban planning challenges associated with developing countries in the last 7 years. Furthermore, classifying the urban system elements and the sustainable development goals to be used in a multi-criteria decision analysis.

In Chapter 3, continuing with the first phase of the systems engineering approach was categorising the tools/techniques found in the systematic literature review into groups for content analysis. The categories included units of observation, paradigms, units of analysis, qualitative/quantitative and types of approaches. Thereafter, the tools/techniques were analysed toward a solution-specific approach. This means that they resembled tools/techniques that were orientated for implementation and specifically sustainable practices. Revealing 70 tool/techniques that went into the multi-criteria decision analysis.

In Chapter 4, final part of the input identification phase of the system engineering approach, the multi-criteria decision analysis was developed. Combing the urban system elements and sustainable development goals featured in Chapter 2, Section 2.5. An analytical hierarchy process (AHP) using a pairwise comparison and a weighting method to determine a new quantitative scheme to differentiate between the tools/techniques. The new quantitative measuring scheme formed the triple bottom line scores which divided points among the social, environmental and economic states according to their AHP score. Allowing for tools/techniques to classify along a balanced sustainable state.

In Chapter 5, the second phase of the systems engineering approach, requirement analysis. A requirements specification was developed according to five requirement types (Huff, Tranfield and Van Aken, 2006): (i) functional requirements, (ii) user requirements, (iii) design restrictions, (iv) attention points, and (v) boundary conditions. This analysis identified the requirements necessary to develop a framework that would achieve the aim and objectives of the research.

In Chapter 6, the third phase of the systems engineering approach, functional analysis. Using four activities of the functional analysis to develop the framework: (i) inputs, (ii) controls, (iii) enablers, and (iv) outputs. The requirements specification was the input, constraints were used to control the framework and the enabler was functional flow block diagrams. These gave insight into the functions needed to perform to achieve the requirements listed in the previous chapter.

In Chapter 7, was the first part of the final phase of the systems engineering approach. Designing the SUPA DSF. This was according to guideline from the requirements specification and the functional analysis. Combing the tools and techniques landscape with the triple bottom line scores to evaluate user input criteria determined the appropriate tool/technique to support a user with their sustainable urban planning project.

In Chapter 8, was the second part of the final phase of the systems engineering approach. Containing the evaluating strategy of the SUPA DSF. The evaluation strategy had two stages: verification and validation. The verification had two steps, evaluating the requirements specification, and conducting a theoretical verification with SMEs. The feedback from the interviews were refined into the SUPA DSF. Lastly, a validation of the SUPA DSF was performed with three case studies, one for each of the sustainable urban planning challenges identified in the SLR. The SUPA DSF was validated for its relevancy and practicability.

## 9.2 Contribution to the sustainable urban planning industry

At the start of the research, it was identified that in the urban planning spectrum of developing countries more emphasis was given to economic endeavours versus social equality and environmental stability. This was apparent in the SLR which revealed the challenges facing progress toward sustainable urban systems. Therefore, the next step was categorizing the tools and techniques used to solve these challenges. By adopting the pragmatism philosophy, this directed the research to combine the current problems, practices and eventually find the relevance in real world situations (Saunders, Lewis and Thornhill, 2009). The combination of the problems and practices was made possible with the multi-criteria decision analysis. This method of evaluation may be a useful contribution to urban planning in developing countries. Conducting an AHP will sometimes carry subjectivity. In the case of comparing urban system elements and sustainable development goals to which is more important in achieving sustainability for a city, does need some subjectivity to find results. However, this opens the conversation to discuss the trade-offs and to produce new methods of sustainable analysis that quantify the differences more accurately in various contexts.

Designing the SUPA DSF can be useful in the urban planning spectrum. This was verified by SMEs in the theoretical verification interviews. However, the decision making process would need to be better understood for the SUPA DSF to have more impact. Nevertheless, the SUPA DSF can lead users to consider new options that weren’t considered. Sustainable thinking is holistic and strategic. Taking consideration of the future needs of a city is the first step in approaching urban planning challenges. To evaluate the future needs and challenges in developing countries, more data and information are required to have better predictions. However, this is the developing countries' initial hurdle. Increasing the capacity and expertise to capture and interpret urban system data.

The SUPA DSF should be used as an initial step when urban planners are considering sustainable projects. Because it provides a guideline for an executable plan that can be investigated further. In conclusion, this research contributes to transitions of sustainable urban planning practices. Not only with the SUPA DSF but also with the SLR, tools and techniques landscape and the structured multi-criteria decision analysis. The contribution of the research lies in the systems engineering approach with a development process that considered sustainable tools/techniques that were unnoticed.

## 9.3 Addressing the research objectives

The aim and objective as set out in Chapter 1 have been met by this research study. The aim was to develop a framework that would assist urban planners with sustainable urban planning projects. This was achieved by developing the SUPA DSF. Table 9.1 gives an overview of the objectives and in which chapters they were accomplished.

*Table 9.1: Research aim and objectives accomplished*

| Research objectives | Chapter and section numbers |
|---|---|
| **RO1: Identify the prevalent challenges that disrupts sustainable urban planning** | |
| a. Perform a systematic literature review (SLR) using a Boolean search with synonyms of (urban planning, challenges & sustainability). | Chapter 2, Section 2.2 |
| b. Identify effectiveness and bias of the systematic literature review. | Chapter 2, Section 2.2.5 |
| c. Disseminate the challenges from all the relevant literature review papers and display them in a matrix regarding the sustainable urban planning topics. | Appendix A.1 |
| d. Group the prevalent topics together and focus on the challenges that occur the most frequently. | Chapter 2, Section 2.4 |
| e. Identify connection of urban system elements and sustainable development goals to the challenges. | Chapter 2, Section 2.5 & 2.6 |
| **RO2: Determine the best method to increase the success of sustainable urban planning in developing countries.** | |
| a. Investigate the current tools and techniques that are used for urban planning today. | Chapter 3, Section 3.1 |
| b. Categorise tools/techniques that assist urban planning decision making. | Chapter 3, Section 3.2 – 3.6 |
| c. Identify the tools/techniques specific to sustainability practices for assessment in requirement specification. | Chapter 3, Section 3.8 |
| **RO3: Perform a requirements specification to design a research product.** | |
| a. Identify the connections with the challenges addressed in the tools and techniques landscape using a multi-criteria decision analysis. | Chapter 4, Section 4.1 – 4.5 |
| b. Identify the requirements, restrictions and boundaries contributing toward a research product that achieves the aim of the research. | Chapter 5, Section 5.1 |
| **RO4: Develop a research product for sustainable urban planning in developing countries.** | |
| a. Undertake a functional analysis of the requirements specification. | Chapter 6, Section 6.4 |
| b. Design a research product that will address the aim of the study. | Chapter 7, Section 7.2 |
| **RO5: Perform verification and validation processes** | |
| a. Develop an evaluation strategy to present to SMEs with verification outcomes. | Chapter 8, Section 8.1 – 8.2 |
| b. Update and adapt Sustainable Urban Planning Assistant Decision Support Framework (SUPA DSF) regarding feedback from SMEs. | Chapter 8, Section 8.3 |
| c. Perform case studies that cover the three sustainable urban planning challenges to identify the SUPA DSF's relevancy and practicability. | Chapter 8, Section 8.4 – 8.7 |

## 9.4 Limitations

All relevant topics couldn't be explored in depth. For instance, the domain of decision making within the field of urban planning. The SUPA DSF needs better understanding of the decision making process within the urban planning authorities. This domain was not the main concern for the research objectives. However, spending more time to understand the context specific dilemmas that occur within urban planning decision making. This would've given the research more depth and targeted more specific context.

A second limitation is regarding the research is rooted in the urban planning trade. The SMEs used in the verification process did not have experience in the Industrial engineering discipline. All SMEs were highly qualified experts in a systems perspective with fields of knowledge necessary for the research.

The evaluation of the real world application of the SUPA DSF is limited with the case studies that were applied. A case study which would have granted real feedback and results in a real world setting would have been more beneficial. The SME verification interviews articulate the frameworks relevance and practicability as they all agreed that the SUPA DSF could contribute to improving sustainable urban planning in developing countries.

## 9.5 Future work

It is advisable that the following opportunities are explored as future studies, as they build on the purpose of the research investigation.

The first recommendation is for the framework. The SUPA DSF needs better understanding of the decision making process within the urban planning authorities. At the start of the research a decision support framework was not the definitive direction for the research product. Until the requirement specification lead to the best option to achieve the aim of the research was a decision support framework. Therefore, the next course for the SUPA DSF would be to understand the current decision making climate for urban planning. This would require additional literature to investigate how the authorities decide on urban planning projects in developing countries. Given urban planners are seldom the ones with enough power to choose which sustainable tool/technique to implement. This additional layer would increase the rigor and context for the SUPA DSF to have greater impact on developing countries' urban planning.

A point on the framework is that there's a quite a high degree of endogeneity. But the framework would perform better if it was able to manage trade-offs within the triple bottom line. Which would be much more focused. More often for urban planners it's not about selecting all three sustainable states. However, it's about finding the suitable trade-off between the sustainable states. The SUPA DSF would require more literature into urban planning at the technical and operational level. A more focused approach that assists urban planners with a mathematical/statistical model which find the beneficial option surrounded by many constraints. Overall, reducing risks and improving transparency for urban planners.

Another recommendation for the research is to adapt into a teaching outlet. As has been mentioned in the theoretical verification refinements in Section 8.3 , the SUPA DSF could be helpful to urban planning student. Guiding students to understand the holistic opportunities of sustainable urban planning. The framework would need more accuracy regarding the multi-criteria decision analysis. Improving quality of the pairwise comparison between urban system elements and the sustainable development goals would be very beneficial for the students using the framework.

## 9.6 Conclusion: Chapter 9

This chapter concludes the research, which investigated the challenges faced by urban planners in developing countries. Addressed this with the SUPA DSF. This chapter is an overview of the research provided and discussed the aim and objectives that were achieved. The contributions made to the research of sustainable urban planning in developing countries. Furthermore, discussed suggestions for possible future work that could be built on the discoveries of this research investigation.

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# Appendix A – Additional information from systematic literature review

In this appendix, additional information regarding the systematic literature reviews conducted to develop the SUPA is found.

The following sections are included:

A.1 – Challenges Landscape

A.2 – Tools and Techniques Landscape

A.3 – Multi-Criteria Decision Analysis

## A.1 – Challenges landscape

*Table A. 1: All tables counting the urban planning challenges from the SLR*

| Sustainability | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ICT | Complexity | Prediction | Sustainability | Resource management | Data analytics | Planning | Developing countries | Environment | Society | Urban Sprawl | Technology | Climate Change | Urbanisation | Population Growth | Transportation | Economy |
| 2 | 2 | 2 | 2 | 4 | 1 | 11 | 3 | 4 | 3 | 3 | 2 | 1 | 1 | 1 | 1 | 3 |
| 46 | | | | | | | | | | | | | | | | |

| Urban Planning | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sustainability | Society | Complexity | Data scarcity | Transportation | Traditions | Technology | Adaption | City | Environment | Public participation | Developing country | Climate Change | Resilience | Food security | Resource management | Energy | Urban Sprawl | Government | Urbanisation | Population growth | Economy |
| 19 | 17 | 8 | 3 | 6 | 1 | 8 | 5 | 3 | 10 | 6 | 6 | 4 | 2 | 4 | 4 | 3 | 7 | 6 | 5 | 3 | 7 |
| 137 | | | | | | | | | | | | | | | | | | | | | |

| Urbanisation | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sustainability | Technology | Society | Developing country | Food security | Environment | Economic | Energy | Prediction | Transportation | Urban Sprawl | Government | Resource management | Population growth | Planning |
| 14 | 2 | 10 | 9 | 6 | 7 | 5 | 1 | 1 | 3 | 1 | 2 | 2 | 3 | 4 |
| 70 | | | | | | | | | | | | | | |

| Urban Sprawl | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Environment | Planning | Society | Energy | Transportation | Sustainability | Food security | Urbanisation | Developing Country | Resource Management | Economy |
| 7 | 10 | 9 | 2 | 11 | 8 | 3 | 2 | 2 | 2 | 3 |
| 59 | | | | | | | | | | |

| Society | | | | |
|---|---|---|---|---|
| Environment | Complexity | Sustainability | Planning | Economy |
| 3 | 1 | 1 | 2 | 0 |
| 7 | | | | |

| Environmental | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Resource management | Society | Economy | Planning | Sustainability | Urbanisation | Climate Change | Developing country | Urban Sprawl | Population Growth | Food security |
| 2 | 2 | 3 | 5 | 4 | 1 | 1 | 1 | 1 | 1 | 2 |
| 23 | | | | | | | | | | |

| Economic | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Environment | Resource management | Developing country | Energy | Transportation | Planning | Society | Urban Sprawl | Sustainability |
| 5 | 2 | 1 | 1 | 4 | 2 | 3 | 2 | 5 |
| 25 | | | | | | | | |

| Developing country | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planning | Infrastructure | Sustainability | Economic | Food security | Sustainability | Society | Resource management | Environment | Climate Change | Urbanisation | Transportation | Urban sprawl | Technology | Population Growth | Energy |
| 5 | 1 | 4 | 6 | 4 | 4 | 6 | 4 | 3 | 4 | 4 | 1 | 3 | 2 | 2 | 2 |
| 55 | | | | | | | | | | | | | | | |

| Population Growth | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Developing country | Planning | Water scarcity | Food security | Resource Management | Economic | Energy | Environment | Urban Sprawl | Urbanisation | Society | Sustainability | Government |
| 10 | 5 | 2 | 2 | 3 | 2 | 2 | 2 | 3 | 2 | 1 | 1 | 3 |
| 38 | | | | | | | | | | | | |

| Government | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Society | Urban Sprawl | Transportation | Resource management | Energy | Economy | Sustainability | Urbanisation | Adaption | Developing country | Planning |
| 3 | 3 | 3 | 2 | 1 | 1 | 4 | 1 | 1 | 2 | 3 |
| 24 | | | | | | | | | | |

| Energy | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Resource management | Society | Planning | City | Government | Economy | Climate change | Transportation | Sustainability | Environment |
| 3 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 6 |
| 20 | | | | | | | | | |

| Smart Growth | | | | |
|---|---|---|---|---|
| Planning | Society | Transportation | Environment | Sustainability |
| 1 | 2 | 1 | 1 | 2 |
| 7 | | | | |

| Food security | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sustainability | Developing country | Planning | Urbanisation | Economy | Environment | Technology | Urban Sprawl | Population Growth | Society |
| 4 | 1 | 3 | 1 | 4 | 2 | 1 | 1 | 1 | 3 |
| 21 | | | | | | | | | |

| Climate change | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Adaption | Resilience | Food security | Planning | Sustainability | Energy | Social | Economy | Urbanisation | Resource Management | Transportation |
| 1 | 3 | 1 | 3 | 3 | 1 | 3 | 2 | 1 | 1 | 1 |
| 20 | | | | | | | | | | |

| Resilience | | | | |
|---|---|---|---|---|
| Planning | Environment | City | Climate Change | Sustainability |
| 2 | 1 | 1 | 1 | 2 |
| 7 | | | | |

| Data Scarcity | | |
|---|---|---|
| Sustainability | Energy | Planning |
| **2** | **1** | **3** |
| **6** | | |

| Transportation | | | | | |
|---|---|---|---|---|---|
| City | Economy | Environment | Urban Sprawl | Planning | Population Growth |
| **1** | **2** | **1** | **2** | **1** | **1** |
| **8** | | | | | |

| Prediction and Adaptation | | | | |
|---|---|---|---|---|
| City | Planning | Planning | Sustainability | Resilience |
| **1** | **2** | **2** | **2** | **1** |
| **8** | | | | |

## A.2 – Tools and techniques landscape

*Table A. 2: All Tools and Techniques listed by Authors*

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Larasati N., Handayaningsih S., Sumarsono S.,** | **Smart sustainable city application: Dimensions and developments : cion of the foremost cultural centers of a developing country,** | **Smart Sustainable City (SSC)** | Smart city | Urban/Formal | ICT | Qualitative | Solution-Specific |
| | | **Information and Communications Technology (ICT)** | Smart city | Urban/Formal | ICT | Qualitative | Problem-Generic |
| | | **IT-based services** | Smart city | Urban/Formal | ICT | Qualitative | Problem-Generic |
| | | **Semantic web, Cloud computing, and the Internet of Things (IoT)** | Smart city | Urban/Formal | ICT | Qualitative | Problem-Generic |
| | | **Traffic management** | Smart city | Urban/Formal | ICT | Quantitative | Solution-Generic |
| | | **Video analytics** | Smart city | Urban/Formal | ICT | Qualitative | Solution-Generic |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Li W., Zhou W., Han L., Qian Y.,** | **Uneven urban-region sprawl of China's megaregions and the spatial relevancy** | **Landsat Thematic Mapper** | Sustainable development | Rural/Formal | Sprawl | Quantitative | Problem-Generic |
| | | **Land Utilization Index (LUI)** | Sustainable development | Rural/Formal | Sprawl | Quantitative | Problem-Specific |
| | | **Regional Sprawl Index (ReSI)** | Sustainable development | Rural/Formal | Sprawl | Quantitative | Problem-Specific |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **in a multi-scale approach,** | **Urban-area Sprawl Index (UrSI)** | Sustainable development | Rural/Formal | Sprawl | Quantitative | Problem-Specific |

| **Author(s)** | **Title** | **Tool/Technique** | **Paradigm** | **Unit of Analysis** | **Unit of observation** | **Quantitative/Qualitative** | **Type of approach** |
|---|---|---|---|---|---|---|---|
| **Moroke T., Schoeman C., Schoeman I.,** | **Developing a neighbourhood sustainability assessment model: An approach to sustainable urban development,** | **Successful Neighbourhood Model (SNM)** | Sustainable development | Rural/Formal | Sprawl | Quantitative | Solution-Specific |
| | | **Analytic hierarchy process (AHP)** | Sustainable development | Rural/Formal | Sprawl | Quantitative | Solution-Generic |

| **Author(s)** | **Title** | **Tool/Technique** | **Paradigm** | **Unit of Analysis** | **Unit of observation** | **Quantitative/Qualitative** | **Type of approach** |
|---|---|---|---|---|---|---|---|
| **Artmann M., Kohler M., Meinel G., Gan J., Ioja I.-C.,** | **How smart growth and green infrastructure can mutually support each other — A conceptual framework for compact and green cities,** | **Smart Growth Network (SGN)** | Sustainable development | Urban/Formal | Sprawl | Quantitative | Solution-Specific |
| | | **Systemic conceptual framework for compact and green cities** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Solution-Specific |
| | | **Smart-compact-green city framework** | Smart city | Urban/Formal | ICT | Qualitative | Solution-Specific |
| | | **Multi-object approach** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Problem-Generic |
| | | **Indicators** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Generic |
| | | **ICT** | Smart cities | Urban/Formal | ICT | Qualitative | Problem-Generic |
| | | **Transdisciplinary approach** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Generic |
| | | **IOER monitor** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **GIS analysis** | Smart city | Urban/Formal | ICT | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Shabatura L., Bauer N., Iatsevich O.,** | **Socio-Cultural Problems of Sustainable Urban Environment,** | **Landscape design** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Grădinaru S.R., Triboi R., Iojă C.I., Artmann M.,** | **Contribution of agricultural activities to urban sustainability: Insights from pastoral practices in Bucharest and its peri-urban area,** | **Quick Bird** | Sustainable development | Rural/Informal | Sprawl | Qualitative | Problem-Generic |
| | | **Interviews** | Sustainable development | Rural/Informal | Social | Qualitative | Problem-Generic |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Masterson V.A., Mahajan S.L., Tengö M.** | **Photovoice for mobilizing insights on human well-being in complex social-ecological systems: Case studies from Kenya and South Africa** | **Photovoice** | Sustainable development | Rural/Informal | Social | Qualitative | Problem-Generic |
| | | **Participatory photography** | Sustainable development | Rural/Informal | Social | Qualitative | Problem-Generic |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Tutu R., Busingye J.D.** | **Building resilient societies in Africa for the future: Conceptual considerations and possible resilience constituents** | **United Nations Sustainable Development Goals (SDGs)** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **Anticipatory Action Learning** | Adaption Planning | Urban/Formal | Resilience | Qualitative | Problem-Generic |
| | | **Land-use regulation** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |
| | | **UN-Habitat's City Resilience Profiling Program's (UNISDR)** | Adaption Planning | Urban/Formal | Resilience | Qualitative | Problem-Specific |
| | | **Youth Resilience Framework, the Megacity Resilience Framework, the Dynamic Resilience Model, and the Resilience–Transition–Transformation Framework** | Adaption Planning | Urban/Formal | Resilience | Qualitative | Problem-Specific |

| **Author(s)** | **Title** | **Tool/Technique** | **Paradigm** | **Unit of Analysis** | **Unit of observation** | **Quantitative/Qualitative** | **Type of approach** |
|---|---|---|---|---|---|---|---|
| **Bibri S.E.** | **A foundational framework for smart sustainable city development: Theoretical, disciplinary, and discursive dimensions and their synergies** | **ICT** | Smart city | Urban/Formal | ICT | Qualitative | Problem-Generic |
| | | **Pervasive computing** | Smart city | Urban/Formal | ICT | Quantitative | Problem-Generic |
| | | **Big data analytics techniques** | Sustainable urban planning | Urban/Formal | ICT | Quantitative | Problem-Generic |
| | | **Cloud computing** | Smart City | Urban/Formal | ICT | Quantitative | Problem-Generic |
| | | **Hadoop MapReduce** | Smart City | Urban/Formal | ICT | Quantitative | Problem-Specific |
| | | **Data-driven decision making (DDD)** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Solution-Generic |
| | | **Cross Industry Standard Process for Data Mining (CRISP–DM)** | Smart city | Urban/Formal | ICT | Quantitative | Problem-Generic |
| | | **Artificial Inteligence (AI)** | Smart city | Urban/Formal | ICT | Quantitative | Solution-Generic |
| | | **Simulation and modelling** | Smart city | Urban/Formal | ICT | Quantitative | Problem-Generic |
| | | **Systems engineering** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Laffta S., Al-Rawi A.** | **Green technologies in sustainable urban planning** | **Sustainable water management** | Sustainable development | Urban/Formal | Water management | Quantitative | Solution-Specific |
| | | **Green technologies** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |
| | | **Environmental Technologies (ET)** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |
| | | **Information Technologies (IT)** | Smart city | Urban/Formal | ICT | Quantitative | Problem-Specific |
| | | **Communications Technologies (CT)** | Smart city | Urban/Formal | ICT | Quantitative | Problem-Specific |
| | | **Renewable technologies** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |
| | | **Smart grid** | Smart city | Urban/Formal | ICT | Quantitative | Problem-Specific |
| | | **Sustainable and green infrastructure** | Eco-City | Urban/Formal | Green City | Qualitative | Solution-Specific |
| | | **Green Road Concept** | Sustainable development | Urban/Formal | Sprawl | Qualitative | Solution-Specific |
| | | **Eco-Town** | Eco-City | Urban/Formal | Green City | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Aburas M.M., Ho Y.M., Ramli M.F., Ash'aari Z.H.** | **Monitoring and assessment of urban growth patterns using spatio-temporal built-up area analysis** | **Mapping urban growth patterns and land-use changes** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |
| | | **Change detection of images** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Problem-Generic |
| | | **Shannon's Entropy approach and GIS techniques** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |
| | | **Remoute Sensing (RS)** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Problem-Specific |
| | | **Urban Expansion Intensity Index (UEII)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Zhan Q., Zou F., Zhang W., Xiao Y.** | **Research and practice on disaster prevention planning in villages based on planning support system overview: Potential public policies on spatial planning for sustainable urban forms (A Case Study)** | **Prediction map** | Adaption Planning | Rural/Informal | Disaster prevention | Quantitative | Problem-Specific |
| | | **PSS (Planning support system)** | Adaption Planning | Rural/Informal | Disaster prevention | Qualitative | Problem-Specific |
| | | **UAV (Unmanned aerial vehicle)** | Smart City | Rural/Informal | Data Collection | Qualitative | Problem-Generic |
| | | **Spatial autocorrelation model** | Sustainable urban planning | Rural/Informal | Urban form | Quantitative | Problem-Specific |
| | | **3S (GIS, RS and GPS)** | Smart City | Rural/Informal | Data Collection | Quantitative | Problem-Specific |
| | | **ArcSDE** | Smart City | Rural/Informal | Data Collection | Quantitative | Problem-Specific |

| **Author(s)** | **Title** | **Tool/Technique** | **Paradigm** | **Unit of Analysis** | **Unit of observation** | **Quantitative/Qualitative** | **Type of approach** |
|---|---|---|---|---|---|---|---|
| **Randhawa A., Kumar A.** | **Exploring sustainability of smart development initiatives in India** | **Smart development** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |
| | | **ICT** | Smart city | Urban/Formal | ICT | Quantitative | Problem-Generic |
| | | **Private participation** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Generic |
| | | **Public participation** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Generic |
| | | **Retrofitting** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Solution-Specific |
| | | **Gross domestic product (GDP)** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Generic |
| | | **Smart City Proposal (SCP)** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |

| **Author(s)** | **Title** | **Tool/Technique** | **Paradigm** | **Unit of Analysis** | **Unit of observation** | **Quantitative/Qualitative** | **Type of approach** |
|---|---|---|---|---|---|---|---|
| **Xu Y., Ren C., Ma P., Ho J., Wang W., Lau K.K.-L., Lin H., Ng E.** | **Urban morphology detection and computation for urban climate research** | **Weather research and forecasting (WRF)** | Eco-City | Urban/Formal | Climate change | Quantitative | Problem-Specific |
| | | **Local climate zone (LCZ)** | Eco-City | Urban/Formal | Climate change | Quantitative | Problem-Specific |
| | | **Sky view factor (SVF)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |
| | | **Frontal area index (FAI)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |
| | | **Building coverage ratio (BCR)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |
| | | **Building height (BH)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |
| | | **Building volume density (BVD)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |
| | | **Roughness length (RL)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |
| | | **Morphology extraction technologies** | Smart City | Urban/Formal | Data collection | Qualitative | Problem-Specific |
| | | **Building footprint extraction** | Smart City | Urban/Formal | Data collection | Quantitative | Problem-Specific |
| | | **Urban Climatic Map (UCMap)** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **SOLWEIG** | Eco-City | Urban/Formal | Climate change | Quantitative | Solution-Specific |
| | | **PALM** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Solution-Specific |
| | | **World Urban Database and Access Portal Tools (WUDAPT)** | Sustainable urban planning | Urban/Formal | Data collection | Quantitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Currie P.K., Musango J.K.** | **African Urbanization: Assimilating Urban Metabolism into Sustainability Discourse and Practice** | **Human Development Index (HDI)** | Sustainable Development | Urban/Informal | Social | Quantitative | Problem-Specific |
| | | **Urban Metabolism** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |
| | | **Material flow analysis (MFA)** | Smart City | Urban/Formal | Data Collection | Quantitative | Problem-Specific |
| | | **Domestic material consumption (DMC)** | Smart City | Urban/Formal | Data Collection | Quantitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Brelsford C., Lobo J., Hand J., Bettencourt L.M.A.** | **Heterogeneity and scale of sustainable development in cities** | **Human Development Index (HDI)** | Sustainable development | Urban/Informal | Social | Quantitative | Problem-Specific |
| | | **Secure Tenure Index (STI)** | Sustainable development | Urban/Informal | Sprawl | Qualitative | Problem-Specific |
| | | **Moran's I** | Sustainable development | Urban/Informal | Sprawl | Quantitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Ahmed K.G.** | **Designing sustainable urban social housing in the United Arab Emirates** | **Investigation tools** | Sustainable urban planning | Rural/Formal | Planning | Qualitative | Problem-Generic |
| | | **ESTIDAMA** | Sustainable urban planning | Rural/Formal | Planning | Qualitative | Solution-Specific |
| | | **International Renewable Energy Agency (IRENA)** | Sustainable urban planning | Rural/Formal | Planning | Qualitative | Problem-Specific |
| | | **New Urbanism** | Sustainable urban planning | Rural/Formal | Planning | Qualitative | Solution-Specific |
| | | **Conceptual Design Matrix for Sustainable Urban Form** | Sustainable urban planning | Rural/Formal | Urban form | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Wicaksono A.D.** | **Control mechanisms in the third-generation planning. Case study: Control to realize sustainable cities** | **Neotraditional Development and Urban Containment** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |
| | | **Uexkuell theory** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Generic |
| | | **Uexkuell model** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Generic |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Hemani S., Das A.K., Chowdhury A.** | **Influence of urban forms on social sustainability: A case of Guwahati, Assam** | **Social Capital Assessment Tool** | Sustainable urban planning | Rural/Formal | Planning | Qualitative | Problem-Specific |
| | | **Morphological study** | Sustainable development | Rural/Formal | Urban Form | Qualitative | Problem-Specific |
| | | **Base Mapping** | Sustainable development | Rural/Formal | Urban Form | Qualitative | Problem-Specific |
| | | **Overlay mapping** | Sustainable development | Rural/Formal | Urban Form | Qualitative | Problem-Specific |
| | | **Land-use Ratio** | Sustainable development | Rural/Formal | Urban Form | Quantitative | Problem-Specific |
| | | **Land-use Diversity** | Sustainable development | Rural/Formal | Urban Form | Quantitative | Problem-Specific |
| | | **Population Density** | Sustainable development | Rural/Formal | Urban Form | Quantitative | Problem-Specific |
| | | **Compactness Ratio** | Sustainable development | Rural/Formal | Urban Form | Quantitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Battersby J.** | **Food system transformation in the absence of food system planning: The case of supermarket and shopping mall retail expansion in Cape Town, South Africa** | **Timeseries analysis** | Eco-city | Urban/Informal | Food System | Qualitative | Problem-Generic |
| | | **Public participation** | Eco-city | Urban/Informal | Food System | Qualitative | Solution-Generic |
| | | **Public–private partnerships** | Eco-city | Urban/Informal | Food System | Qualitative | Solution-Generic |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Bai M., Zhou S., Zhao M., Yu J.** | **Water use efficiency improvement against a backdrop of expanding city agglomeration in developing countries-A case study on industrial and agricultural water use in the Bohai Bay Region of China** | **Industrial water use efficiency** | Sustainable development | Urban/Informal | Water management | Qualitative | Solution-Generic |
| | | **Non-radial directional distance function method** | Sustainable development | Urban/Informal | Water management | Quantitative | Problem-Generic |
| | | **Data envelopment analysis model (DEA)** | Sustainable development | Urban/Informal | Water management | Quantitative | Solution-Generic |
| | | **Non-radial Malmquist water use performance index** | Sustainable development | Urban/Informal | Water management | Quantitative | Problem-Generic |
| | | **Maximum potential reduction index of pollutants (MPRI)** | Sustainable development | Urban/Informal | Water management | Quantitative | Problem-Specific |
| | | **Water stress index (WSI) and Water degradation possibility (WDP)** | Sustainable development | Urban/Informal | Water management | Quantitative | Problem-Specific |
| | | **Grey water footprint** | Sustainable development | Urban/Informal | Water management | Quantitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Slaev A.D., Nedovic-Budic Z.,** | **The challenges of implementing sustainable development: The case of Sofia's master plan** | **Floor area ratios (FAR)** | Sustainable urban planning | Rural/Formal | Urban form | Qualitative | Problem-Specific |
| | | **Indicators** | Smart city | Urban/Formal | Data collection | Qualitative | Problem-Generic |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Broto V.C.** | **Energy landscapes and urban trajectories towards sustainability** | **Energy landscapes** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Problem-Specific |
| | | **Analytical framework** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Solution-Generic |
| | | **Coevolution** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **Scheme of Control Agreements (SCAs)** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Roggema R.** | **The future of sustainable urbanism: a redefinition** | **Sustainable urbanism** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Solution-Specific |
| | | **Anti-fragility** | Adaption planning | Urban/Formal | Anti-fragility | Qualitative | Solution-Specific |
| | | **City that plans** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **New Urban Agenda** | Sustainable development | Urban/Formal | Social | Qualitative | Solution-Specific |
| | | **Form follows function** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Generic |
| | | **Layer-approach** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Problem-Generic |
| | | **DCBA** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Solution-Generic |
| | | **Checklists and building codes** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **Green urbanism** | Sustainable development | Urban/Formal | Green city | Qualitative | Solution-Specific |
| | | **Emergism** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Generic |
| | | **Swarm Planning** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Generic |
| | | **Urban coding** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |

| **Author(s)** | **Title** | **Tool/Technique** | **Paradigm** | **Unit of Analysis** | **Unit of observation** | **Quantitative/Qualitative** | **Type of approach** |
|---|---|---|---|---|---|---|---|
| **Habibi S., Zebardast E.** | **How compact are midsize cities in Iran?** | **Confirmatory factor analysis** | Sustainable urban planning | Urban/Formal | Urban Form | Quantitative | Problem-Generic |
| | | **Measure urban forms** | Sustainable urban planning | Urban/Formal | Urban Form | Quantitative | Problem-Specific |
| | | **Exploratory factors analysis** | Sustainable urban planning | Urban/Formal | Urban Form | Quantitative | Problem-Generic |
| | | **Compact city** | Sustainable urban planning | Urban/Formal | Urban Form | Quantitative | Solution-Specific |
| | | **ArcGIS** | Smart City | Urban/Formal | Data collection | Quantitative | Problem-Specific |

| **Author(s)** | **Title** | **Tool/Technique** | **Paradigm** | **Unit of Analysis** | **Unit of observation** | **Quantitative/Qualitative** | **Type of approach** |
|---|---|---|---|---|---|---|---|
| **Zhang X.** | **Sustainable urbanization: a bi-dimensional matrix model** | **Cellular Automata model** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Solution-Generic |
| | | **Sustainable urbanization framework** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Solution-Specific |
| | | **Evaluate sustainable urbanization model** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |
| | | **Coordinated matrix** | Smart City | Urban/Formal | Data collection | Quantitative | Problem-Generic |
| | | **Bi-dimensional matrix** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |

| **Author(s)** | **Title** | **Tool/Technique** | **Paradigm** | **Unit of Analysis** | **Unit of observation** | **Quantitative/Qualitative** | **Type of approach** |
|---|---|---|---|---|---|---|---|
| **Mohareb E., Derrible S., Peiravian F.** | **Intersections of Jane Jacobs' conditions for diversity and low-carbon urban systems: A look at four global cities** | **Framework for Comparing Jacobs' Conditions and GHG Emissions** | Smart City | Urban/Formal | Data collection | Qualitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Ding X., Zhong W., Shearmur R.G., Zhang X., Huisingh D.** | **An inclusive model for assessing the sustainability of cities in developing countries - Trinity of Cities' Sustainability from Spatial, Logical and Time Dimensions (TCS-SLTD)** | **Sustainable development indicators (SDIs)** | Sustainable development | Urban/Formal | Social | Quantitative | Problem-Specific |
| | | **Trinity of cities sustainability** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Solution-Specific |
| | | **Multi-Dimension Framework for Sustainability Assessment (MDFSA)** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **Pressure-State-Response (PSR) framework** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **Vulnerability Framework** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **CRITINC Framework** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |
| | | **Dashboard of Sustainability** | Sustainable urban planning | Urban/Formal | Planning | Quantitative | Problem-Specific |
| | | **enhanced Drivers-Pressures-States-Impacts-Responses framework (eDPSIR)** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Generic |
| | | **Compact coefficient of urban area (CCUA)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Solution-Specific |
| | | **Ecosystem services value (ESV)** | Sustainable development | Urban/Formal | Social | Quantitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Horn A.** | **Urban Growth Management Best Practices: Towards Implications for the Developing World** | **Green belt** | Sustainable development | Rural/Formal | Sprawl | Qualitative | Solution-Specific |
| | | **Bottom-up planning** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Generic |
| | | **Compact city** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Solution-Specific |
| | | **Free-market planning** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Solution-Generic |
| | | **Polycentric networks** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Specht K., Siebert R., Hartmann I., Freisinger U.B., Sawicka M., Werner A., Thomaier S., Henckel D., Walk H., Dierich A.** | **Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings** | **Urban agriculture** | Eco-City | Urban/Formal | Food system | Qualitative | Solution-Specific |
| | | **Green urban architecture** | Eco-City | Urban/Formal | Green City | Qualitative | Solution-Specific |
| | | **ZFarming** | Eco-City | Urban/Formal | Food system | Qualitative | Solution-Specific |
| | | **Edible city** | Eco-City | Urban/Formal | Food system | Qualitative | Solution-Specific |
| | | **Brownfield development** | Eco-City | Urban/Formal | Food system | Qualitative | Solution-Specific |
| | | **Vertical farming** | Eco-City | Urban/Formal | Food system | Qualitative | Solution-Specific |
| | | **Building integrated agriculture (BIA)** | Eco-City | Urban/Formal | Food system | Qualitative | Solution-Specific |
| | | **Eco-effective architecture** | Eco-City | Urban/Formal | Green City | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Russo T., Alfredo K., Fisher J.** | **Sustainable water management in urban, agricultural, and natural systems** | **Indicators** | Sustainable development | Rural/Informal | Water management | Quantitative | Problem-Generic |
| | | **Life Cycle Assessment** | Sustainable development | Rural/Informal | Water management | Quantitative | Solution-Generic |
| | | **Ecological Footprint & Water Footprint** | Sustainable development | Rural/Informal | Water management | Quantitative | Problem-Specific |
| | | **Risk analysis, cost-benefit analysis, and impact assessments** | | Rural/Informal | | Quantitative | Solution-Generic |
| | | **System dynamics modelling** | Sustainable development | Rural/Informal | Water management | Qualitative | Solution-Generic |
| | | **Hydrologic model** | Sustainable development | Rural/Informal | Water management | Qualitative | Solution-Generic |
| | | **Green Revolution** | Eco-City | Rural/Informal | Green City | Qualitative | Solution-Specific |
| | | **Blue Revolution** | Sustainable development | Rural/Informal | Water management | Qualitative | Solution-Specific |
| | | **Water policy** | Sustainable development | Rural/Informal | Water management | Qualitative | Solution-Specific |
| | | **SWAGMAN** | Eco-City | Rural/Informal | Food System | Qualitative | Solution-Specific |
| | | **Ecological Limits of Hydrologic Alteration (ELOHA)** | Sustainable development | Rural/Informal | Water management | Qualitative | Problem-Specific |
| | | **Southern African Development Community (SADC)** | Sustainable development | Rural/Informal | Social | Qualitative | Solution-Generic |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Dur F., Yigitcanlar T., Bunker J.** | **A Spatial-Indexing model for measuring Neighbourhood-Level Land-Use and transport integration** | **Leadership in Energy and Environmental Design (LEED)** | Sustainable urban planning | Rural/Formal | Planning | Qualitative | Solution-Specific |
| | | **Indicator** | Sustainable urban planning | Rural/Formal | Planning | Quantitative | Problem-Generic |
| | | **Water-sensitive urban design (WSUD)** | Sustainable development | Rural/Formal | Water management | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Babalik-Sutcliffe E.** | **Urban Form and Sustainable Transport: Lessons from the Ankara Case** | **Corridor development** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Solution-Specific |
| | | **Non-transport policies** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |
| | | **Transit-oriented development** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |
| | | **Planning for less travel** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |
| | | **Compact city** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Solution-Specific |
| | | **Mixed-use strategy** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Wamsler C., Brink E., Rivera C.** | **Planning for climate change in urban areas: From theory to practice** | **Adaption planning** | Adaption planning | Urban/Formal | Disaster prevention | Qualitative | Solution-Specific |
| | | **Risk reduction** | Adaption planning | Urban/Formal | Disaster prevention | Qualitative | Problem-Specific |
| | | **City-disasters nexus** | Adaption planning | Urban/Formal | Disaster prevention | Qualitative | Solution-Specific |
| | | **Disaster resilient city** | Adaption planning | Urban/Formal | Disaster prevention | Qualitative | Solution-Specific |
| | | **Grey or hard measures** | Adaption planning | Urban/Formal | Disaster prevention | Qualitative | Problem-Specific |
| | | **Biotope Area Factor (BAF)** | Sustainable urban planning | Urban/Formal | Disaster prevention | Quantitative | Problem-Specific |
| | | **Climate planning** | Adaption planning | Urban/Formal | Climate Change | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Chang I.-C.C., Sheppard E.** | **China's Eco-Cities as Variegated Urban Sustainability: Dongtan Eco-City and Chongming Eco-Island** | **The Green New Deal** | Eco-City | Urban/Formal | Green city | Qualitative | Solution-Specific |
| | | **Eco Cities** | Eco-City | Urban/Formal | Green city | Qualitative | Solution-Specific |
| | | **Green-capitalism** | Eco-City | Urban/Formal | Green city | Qualitative | Solution-Specific |
| | | **Township and Village Enterprises (TVEs)** | Sustainable development | Urban/Formal | Social | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Simon D.** | **Climate and environmental change and the potential for greening African cities** | **Green economic investment** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |
| | | **Bus rapid transit (BRT)** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Specific |
| | | **Local Governments for Sustainability's (ICLEI's)** | Sustainable development | Urban/Formal | Social | Qualitative | Solution-Specific |
| | | **Product life cycle (PLC) approach** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Solution-Generic |
| | | **Peri-urban agriculture (UPA)** | Sustainable urban planning | Urban/Formal | Food system | Qualitative | Solution-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Wikantiyoso R., Tutuko P.** | **Planning review: Green city design approach for global warming anticipatory: Surabaya's development plan** | **Green city design** | Eco-City | Urban/Formal | Green city | Qualitative | Solution-Specific |
| | | **Urban design** | Eco-City | Urban/Formal | Green city | Qualitative | Solution-Generic |
| | | **Urban green space** | Eco-City | Urban/Formal | Green city | Qualitative | Solution-Specific |
| | | **Landscape ecology** | Eco-City | Urban/Formal | Green city | Qualitative | Solution-Specific |
| | | **3Rs (Reducing, Reusing, and Recycling)** | Eco-City | Urban/Formal | Green City | Qualitative | Solution-Specific |
| | | **Roof gardening** | Eco-City | Urban/Formal | Food system | Qualitative | Solution-Specific |
| | | **Ecological indicators** | Sustainable urban planning | Urban/Formal | Planning | Qualitative | Problem-Specific |

| Author(s) | Title | Tool/Technique | Paradigm | Unit of Analysis | Unit of observation | Quantitative/Qualitative | Type of approach |
|---|---|---|---|---|---|---|---|
| **Shummadtayar U., Hokao K., Iamtrakul P.** | **Investigating the low-income settlement in an urbanization and urban form a consequences of Bangkok Growing City, Thailand** | **Landsat TM** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Problem-Generic |
| | | **Multi criteria decision analysis (MCDA)** | Sustainable urban planning | Urban/Formal | Urban form | Qualitative | Problem-Specific |
| | | **Analytic hierarchy process (AHP)** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Solution-Generic |
| | | **Concentric circles** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Solution-Specific |
| | | **Remote Sensing** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |
| | | **Built-up area analysis** | Sustainable urban planning | Urban/Formal | Urban form | Quantitative | Problem-Specific |

## A.3 – Multi-criteria decision analysis

*Table A. 3: Urban Systems Elements AHP*

| | | B=i | | | | | | | | | | | | | | | | | | | | | | | 0,080 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Resi** | **Comme** | **Busi** | **Indus** | **Commu** | **Rec** | **Bio** | **Infra** | **Trans** | **Socio** | **avg** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Sj** | | **Norm** |
| A=j | **Residential** | | 1 | 5 | 3 | 1 | 5 | 3 | 1 | 1 | 3 | 2,56 | | 2,420 | 5,975 | 0,198 | 2,420 | 5,975 | 0,198 | 2,420 | 2,420 | 0,198 | 1,491 | Residential | 0,119 |
| | **Commercial** | 1 | | 3 | 1 | | 5 | 1 | | | 1 | 2,00 | 2,420 | | 0,198 | 2,420 | | 5,975 | 2,420 | | | 2,420 | 1,259 | Commercial | 0,101 |
| | **Business** | | | | 1 | | 1 | | | | | 1,00 | | | | 2,420 | | 2,420 | | | | | 0,696 | Business | 0,056 |
| | **Industrial** | | 1 | 1 | | | 1 | | | | | 1,00 | | 2,420 | 2,420 | | | 2,420 | | | | | 0,852 | Industrial | 0,068 |
| | **Community** | 1 | 3 | 5 | 5 | | 1 | 3 | 1 | 3 | 1 | 2,56 | 2,420 | 0,198 | 5,975 | 5,975 | | 2,420 | 0,198 | 2,420 | 0,198 | 2,420 | 1,491 | Community | 0,119 |
| | **Recreational** | | | 1 | 1 | 1 | | | | | 1 | 1,00 | | | 2,420 | 2,420 | 2,420 | | | | | 2,420 | 0,984 | Recreational | 0,079 |
| | **Biophysical assets** | | 1 | 3 | 5 | | 5 | | 3 | 5 | 3 | 3,57 | | 2,420 | 0,198 | 5,975 | | 5,975 | | 0,198 | 5,975 | 0,198 | 1,447 | Biophysical assets | 0,116 |
| | **Infrastructure** | 1 | 5 | 5 | 5 | 1 | 3 | | | 1 | | 3,00 | 2,420 | 5,975 | 5,975 | 5,975 | 2,420 | 0,198 | | | 2,420 | | 1,593 | Infrastructure | 0,128 |
| | **Transport network** | 1 | 5 | 5 | 3 | | 3 | | 1 | | 1 | 2,71 | 2,420 | 5,975 | 5,975 | 0,198 | | 0,198 | | 2,420 | | 2,420 | 1,400 | Transport network | 0,112 |
| | **Socio-economic activities** | | 1 | 3 | 5 | 1 | 1 | | 3 | 1 | | 2,14 | | 2,420 | 0,198 | 5,975 | 2,420 | 2,420 | | 0,198 | 2,420 | | 1,267 | Socio-economic activities | 0,102 |

*Table A. 4: Sustainable Development Goals AHP*

| | | B=i | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,049 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | avg | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Sj | | Norm |
| A=j | 1 | | 1 | 5 | 5 | 5 | 3 | 1 | 3 | 1 | 1 | | | 5 | 5 | 3 | 3 | 5 | 3,29 | | 5,224 | 2,939 | 2,939 | 2,939 | 0,082 | 5,224 | 0,082 | 5,224 | 5,224 | | | 2,939 | 2,939 | 0,082 | 0,082 | 2,939 | 1,971 | 1 | 0,097 |
| | 2 | 1 | | 5 | 5 | 5 | 3 | 1 | 3 | 3 | 3 | | | 5 | 3 | 3 | 3 | 5 | 3,43 | 5,898 | | 2,469 | 2,469 | 2,469 | 0,184 | 5,898 | 0,184 | 0,184 | 0,184 | | | 2,469 | 0,184 | 0,184 | 0,184 | 2,469 | 1,595 | 2 | 0,078 |
| | 3 | | | | 3 | 1 | 1 | | 3 | 3 | 1 | | | 1 | 3 | 1 | 1 | 3 | 1,91 | | | | 1,190 | 0,826 | 0,826 | | 1,190 | 1,190 | 0,826 | | | 0,826 | 1,190 | 0,826 | 0,826 | 1,190 | 1,044 | 3 | 0,051 |
| | 4 | | | | | 3 | | | 1 | 1 | 1 | | | 1 | 3 | 1 | 1 | 3 | 1,67 | | | | | 1,778 | | | 0,444 | 0,444 | 0,444 | | | 0,444 | 1,778 | 0,444 | 0,444 | 1,778 | 0,894 | 4 | 0,044 |
| | 5 | | | 1 | | | | | 1 | 1 | 1 | | | | 3 | 1 | 1 | 5 | 1,75 | | | 0,563 | 3,063 | | | | 0,563 | 0,563 | 0,563 | | | | 1,563 | 0,563 | 0,563 | 10,563 | 1,362 | 5 | 0,067 |
| | 6 | | | 1 | 3 | 3 | | 3 | 5 | 3 | 3 | | 1 | 1 | 1 | 1 | 3 | 5 | 2,54 | | | 2,367 | 0,213 | 0,213 | | 0,213 | 6,059 | 0,213 | 0,213 | | 2,367 | 2,367 | 2,367 | 2,367 | 0,213 | 6,059 | 1,588 | 6 | 0,078 |
| | 7 | 1 | 1 | 3 | 3 | 3 | | | 3 | 1 | 3 | 1 | | 3 | 3 | 1 | 3 | 5 | 2,43 | 2,041 | 2,041 | 0,327 | 0,327 | 0,327 | | | 0,327 | 2,041 | 0,327 | 2,041 | | 0,327 | 0,327 | 2,041 | 0,327 | 6,612 | 1,394 | 7 | 0,069 |
| | 8 | | 3 | | 1 | 1 | | | | | 1 | | | | | | | 1 | 1,40 | | 2,560 | | 0,160 | 0,160 | | | | | 0,160 | | | | | | | 0,160 | 0,566 | 8 | 0,028 |
| | 9 | 1 | | | 1 | 1 | | 1 | 3 | | 1 | | | | 1 | | | 3 | 1,50 | 0,250 | | | 0,250 | 0,250 | | 0,250 | 2,250 | | 0,250 | | | | 0,250 | | | 2,250 | 0,775 | 9 | 0,038 |
| | 10 | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | | 1 | 3 | 1 | 1 | 5 | 1,55 | 0,298 | | 0,298 | 0,298 | 0,298 | | | 0,298 | 0,298 | | | | 0,298 | 2,116 | 0,298 | 0,298 | 11,934 | 1,293 | 10 | 0,064 |
| | 11 | 3 | 3 | 3 | 3 | 5 | 3 | 1 | 5 | 3 | 3 | | 3 | 1 | 3 | 1 | 3 | 5 | 3,00 | 0,000 | 0,000 | 0,000 | 0,000 | 4,000 | 0,000 | 4,000 | 4,000 | 0,000 | 0,000 | | 0,000 | 4,000 | 0,000 | 4,000 | 0,000 | 4,000 | 1,549 | 11 | 0,076 |
| | 12 | 3 | 3 | 3 | 3 | 5 | 1 | 3 | 5 | 3 | 3 | | | 1 | 3 | 1 | 3 | 5 | 3,00 | 0,000 | 0,000 | 0,000 | 0,000 | 4,000 | 4,000 | 0,000 | 4,000 | 0,000 | 0,000 | | | 4,000 | 0,000 | 4,000 | 0,000 | 4,000 | 1,549 | 12 | 0,076 |
| | 13 | | | 1 | 1 | 3 | 1 | | 5 | 3 | 1 | 1 | 1 | | 3 | 3 | 3 | 3 | 2,23 | | | 1,515 | 1,515 | 0,592 | 1,515 | | 7,669 | 0,592 | 1,515 | 1,515 | 1,515 | | 0,592 | 0,592 | 0,592 | 0,592 | 1,425 | 13 | 0,070 |
| | 14 | | | | | | 1 | | 3 | 1 | | | | | | | | 3 | 2,00 | | | | | | 1,000 | | 1,000 | 1,000 | | | | | | | | 1,000 | 0,632 | 14 | 0,031 |
| | 15 | | | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | | 3 | | 3 | 5 | 1,92 | | | 0,852 | 0,852 | 0,852 | 0,852 | 0,852 | 1,160 | 1,160 | 0,852 | 0,852 | 0,852 | | 1,160 | | 1,160 | 9,467 | 1,446 | 15 | 0,071 |
| | 16 | | | 1 | 1 | 1 | | | 3 | 3 | 1 | | | | 3 | | | 5 | 2,25 | | | 1,563 | 1,563 | 1,563 | | | 0,563 | 0,563 | 1,563 | | | | 0,563 | | | 7,563 | 1,245 | 16 | 0,061 |
| | 17 | | | | | | | | 1 | | | | | | | | | | 1,00 | | | | | | | | 0,000 | | | | | | | | | | 0,000 | 17 | 0,000 |

# Appendix B – Research presentations

The following slides were used in the SAIIE conference for the Journal article. Then, followed by the pre-read document for the theoretical verification and theoretical verification interviews presentation.

B.1 – SAIIE conference presentation

B.2 – Pre-read Theoretical Verification Document

B.3 – Theoretical Verification interviews presentation

## B.1 – SAIIE conference


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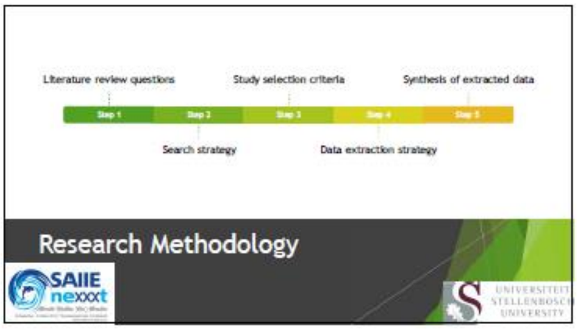


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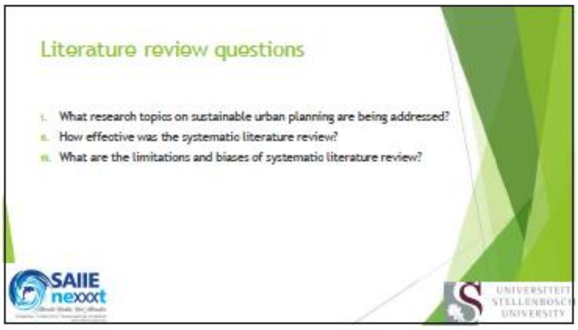


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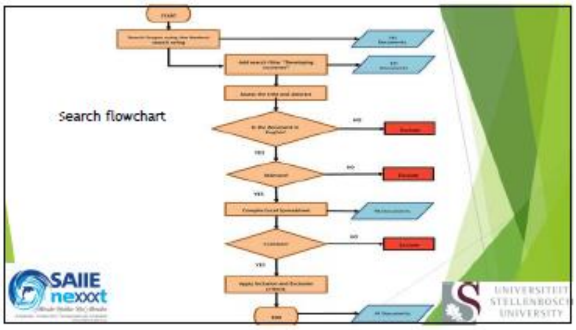


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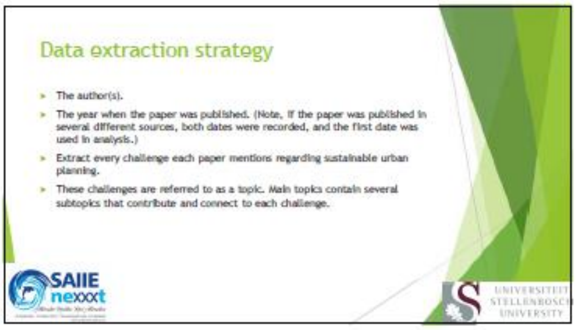


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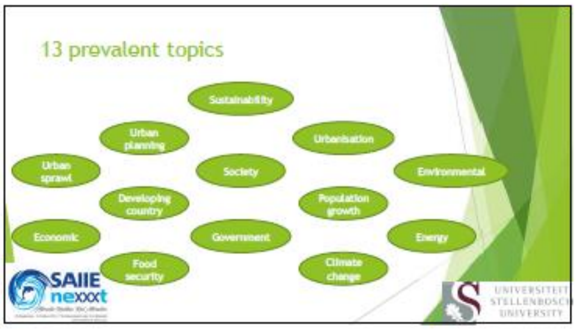


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| MAIN TOPIC | TOPIC TOTAL |
|---|---|
| Urban planning | 137 |
| Urbanisation | 70 |
| Urban sprawl | 59 |
| Developing country | 55 |
| Sustainability | 46 |
| Population growth | 38 |

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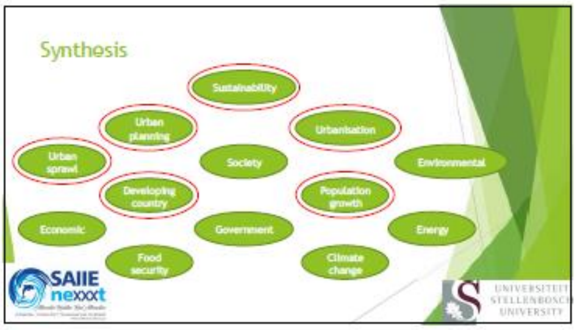


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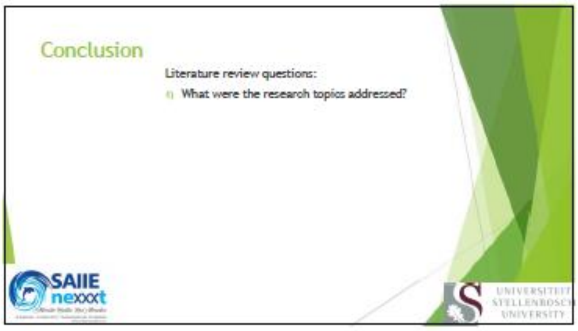


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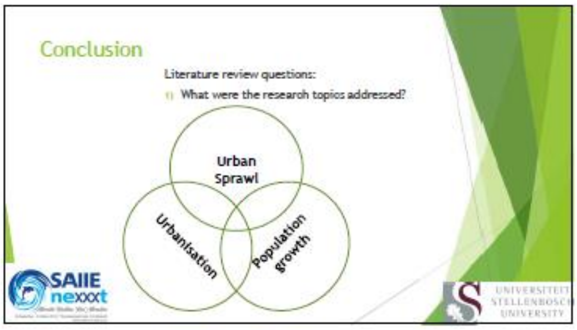


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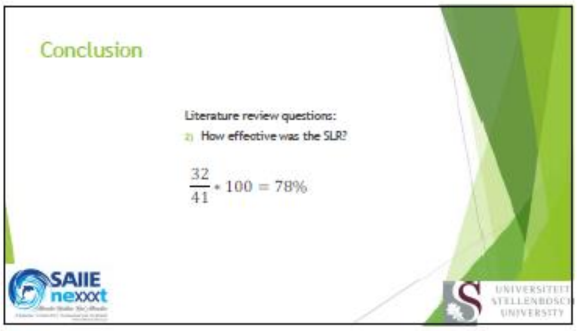


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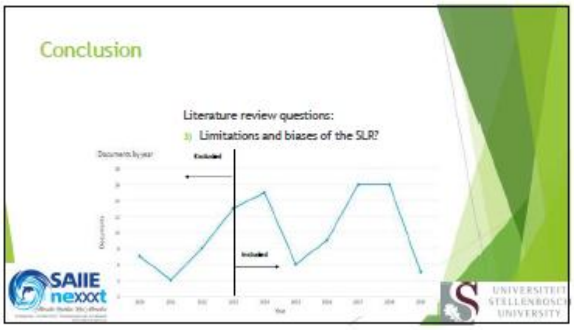


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## B.2 - Pre-read theoretical verification document

### Theoretical Verification Pre-read document

By Andre Jooste

### 1. Verification

Verification is the method of inspection, approving, ensuring, and being confident (Morse *et al.*, 2002). Applying verification strategies are fundamental when guiding research inquiries (Morse *et al.*, 2002). Ensuring the achievement of consistency using strategies is essential with each qualitative project and integrates the responsibility for maintaining reliability and validity to external reviewers' judgements (Morse *et al.*, 2002). The propose of the verification process is thus to verify whether the framework can produce the appropriate tool/technique that increases the sustainability of an urban system.

#### 1.1 Verification overview

The purpose is verifying whether the framework can produce the appropriate tool/technique that increases the sustainability of an urban system. Therefore, the approach needs two stages. Beginning with evaluating the requirements specification (contained in Chapter 5) to achieve the proposed aim and objectives of the research. Thereafter, a theoretical verification of the SUPA decision support framework which satisfies the theory of development for the framework. Particularly, identify and develop a framework that ensures the success of city sustainability, to mitigate the challenges and safeguards the future prosperity in developing countries urban planning. Ensuring there is a balance between the social, environmental and economic stability within an urban system.

#### 1.1.1 Theoretical verification

The literature and information included in Chapter 5 (Requirement Specifications) and Chapter 6 (Functional requirements) must be assessed by SMEs to determine the assumptions and data produced are enough to produce the proposed decision support framework. SMEs would need to verify if alternative literature/methods could increase the frameworks capability to support balancing sustainable urban planning within the given context and scope. The SME assessment must be completed with a questionnaire after they have been presented with the development of the framework.

The following sections will briefly explain the contributing factors to the SUPA decision support framework. Starting with the sustainable urban planning challenges then, the tools and techniques landscape and finally the triple bottom line scores which features a multi-criteria decision analysis.

### 2. Sustainable Urban Planning Challenges

This study seeks to identify the urban planning challenges that arise when planners attempt to initiate sustainable principles. The study used a systematic literature review (SLR) — a structured process that gathers relevant research papers on a specific theme. The challenges related to sustainable urban planning were identified in relevant research papers and synthesised in a large table containing all these challenges. Finally, the pertinent challenges that disrupt urban planners from designing and managing cities sustainably were revealed.

A Boolean search method was used to initiate the SLR. The challenges from all the relevant literature review papers were displayed regarding the topics. The most frequently occurring challenges was the criterion for the prevalent challenges. And lastly, the connection of urban system elements and sustainable development goals to the challenges was identified and presented.

With the use of a matrix containing all the challenges found in the 41 research papers selected in the SLR on sustainable urban planning, the prevalent challenges that form most of a developing country's context were chosen. These dominant challenges were used to develop the links between current urban planning tools and techniques. This provided insight into the gap between current sustainable planning practice and the proposed future planning technique that was developed in this research project. In this section, the challenges contained in the SLR are discussed. The challenges fall under 13 important topics. From this list, six topics have more than 50 challenges.

*Table 1: Six main topics of the systematic literature review*

| Main topic | Primary + Secondary total | Primary total |
|---|---|---|
| Urban planning | 198 | 137 |
| Sustainability | 115 | 46 |
| Developing country | 90 | 55 |
| Urbanisation | 88 | 70 |
| Urban sprawl | 85 | 59 |
| Population growth | 50 | 38 |

The differences between the 'Primary + Secondary total' column and the 'Primary total' column are where these challenges appeared. The 'Primary total' was found only under the specific topic in question. However, the 'Primary + Secondary total' is where all the specific challenges were found throughout the matrix. For example, 'Primary + Secondary total' contained the challenges found under any topic. If a challenge was also associated with an economic and urban planning issue, it was considered within the 'Primary + Secondary total' of economic and urban planning topics respectfully.

To connect the challenges to the urban system, clarification of the elements require identification. Also, to link the challenges to the Sustainable Development Goals (SDGs), a brief understanding of the different goals assign by the United Nations. The three unbiased challenges will be further discussed in terms of two new specifications. Namely, urban system elements and SDGs. The new specifications will be criterions for application to the tool and techniques that will be identified in Chapter 3. Thereafter, a MCDA will be used to evaluate the urban system elements and SDGs for requirements specification in Chapter 4.

.

*Table 2: Urban System Elements*

| Element | Description | Feature/Aspect |
|---|---|---|
| **Residential** | Residential and communal accommodation | Sheltered accommodation, care homes and university residence |
| **Commercial** | Properties for commercial and retail purpose | Supermarkets, shops, storage, warehouses and restaurants |
| **Business** | Office space | Business parks, banks and companies |
| **Industrial** | Properties for industrial purposes | Factories, workshops, and industrial storage facilities |
| **Community** | Properties for community purposes | Educational, health and government services, |
| **Recreational** | Properties for recreational and leisure purpose | Museums, libraries, cinemas and sport activities |
| **Biophysical assets** | Spaces of grassland and woodland | Biodiversity and agriculture |
| **Infrastructure** | Components that allow the city to function | Water, electricity and land resources |
| **Transport network** | The physically linking the different areas of a city | Roads, bridges and fuel resources |
| **Socio-economic activities** | Agents interacting with the city system | People |

*Source: (Dempsey et al., 2010)*

In order to define a city, one needs to understand the elements and complex interactions between elements in an urban system. The urban setting can be represented as different features and aspects to qualify into elements (Dempsey *et al.*, 2010). The urban system elements are listed in .


*Figure 1: Sustainable Development Goals (SDG)*

The most universal and recognised definition of sustainability are the 17 sustainable development goals (SDG) established by the United Nations (UN) in 2015. Figure 1*: Sustainable Development Goals (SDG)* shows the 17 SDG's that provided a consensus for countries around the world to adhere to accomplish by 2030. The elements and the SDG's are used to quantify the urban planning challenges for an analytical hierarchy process (AHP) using a pairwise comparison followed by the least square method for normalisation.

## 3. Tools and Techniques Landscape

The SLR discussed in this paper will be further implemented to uncover the tools and techniques used in current sustainable urban planning practices. A content analysis was performed on the 236 tools and techniques that were found which needed categorisation. The categorisation approach follows a hierarchical structure that leads to tools and techniques identified into established groups: (i) Units of observation, (ii) Paradigms, (iii) Units of analysis, (iv) Quantitative/Qualitative, and (v) Types of approach. These tools and techniques need to connect with the three challenges mentioned in the previous chapter (urbanisation, urban sprawl and population growth).

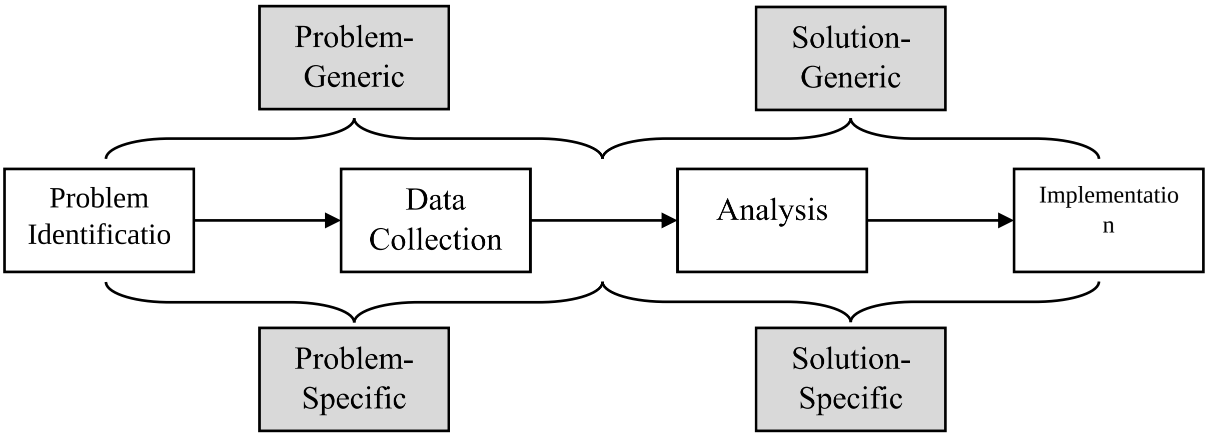



*Figure 2: Differences between the types of approaches*

To link the challenges, the type of approach needed alignment with a solution-specific type. Therefore, the outcome was a sustainable urban planning solution centred toward implementation. There are 70 tools and techniques found that are identified as the methods which will have the greatest effect on urban planning projects toward sustainable outcomes.

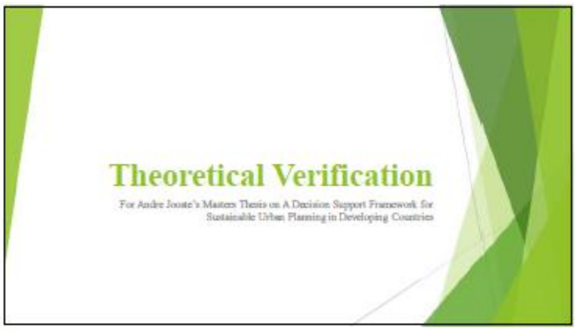
## 4. Triple Bottom Line scores

Stated in the aim of this study, to ensure a balance between the social, environmental and economic stability within a city system. The assessment of the AHP allows an additional scale to differentiate between the tools and techniques. The scores will be spread out among the Triple Bottom Line fundamentals: (i) Social Equality, (ii) Local Environmental, and (iii) Sustainable Economy. This requirement analysis is gathered from an AHP study to reveal a new identification for each tool/ technique. These scores will be used in the functional analysis phase of the systems engineering approach in determining the intervention strategies available for the research product. With the triple bottom line scores calculated, differentiating the tools/techniques into their capabilities of contributing toward the three sustainability factors is now possible.

## 5. Theoretical verification presentation

The pre-read document for the theoretical verification has provided information for the project background. A meeting will be scheduled to have a 30 minute consultation with a presentation to elaborate on the project background, framework development and lastly the actual framework. Thereafter, a short questionnaire will be asked to the SME for feedback on the research. The feedback and findings will be adapted into the research.

## B.3 – Theoretical verification interviews

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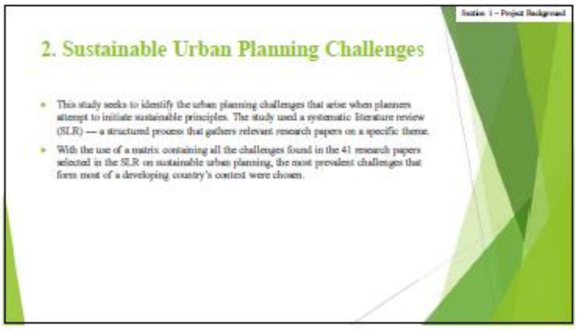


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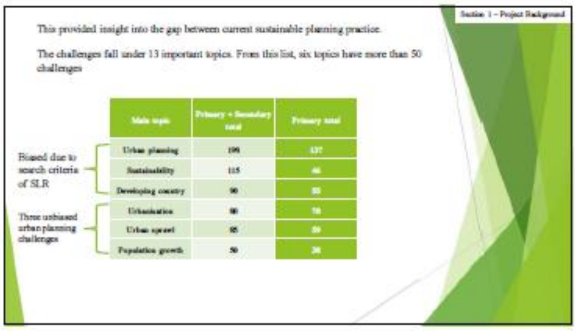


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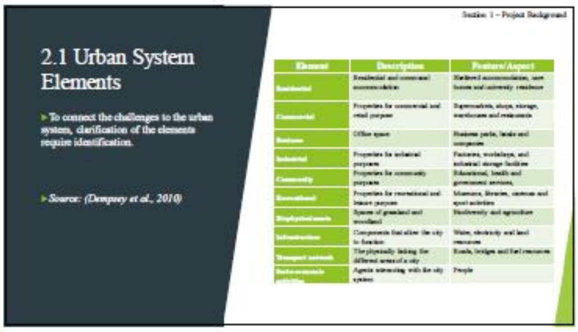


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Section 1 – Project Background
2.2 Sustainable Development Goals (SDG)
The most universal and recognised definition of sustainability are the 17 sustainable development goals (SDG) established by the United Nations (UN) in 2015.
SUSTAINABLE DEVELOPMENT GOALS

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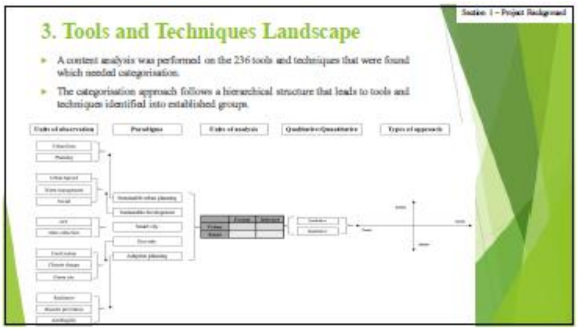
Section 1 – Project Background
3. Tools and Techniques Landscape
A content analysis was performed on the 236 tools and techniques that were found which needed categorisation.
The categorisation approach follows a hierarchical structure that leads to tools and techniques identified into established groups.

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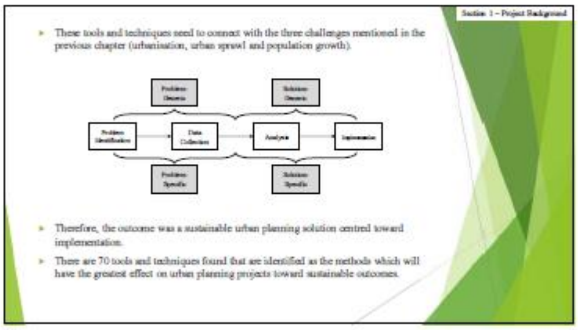
Section 1 – Project Background
These tools and techniques need to connect with the three challenges mentioned in the previous chapter (urbanisation, urban sprawl and population growth).
Therefore, the outcome was a sustainable urban planning solution centred toward implementation.
There are 70 tools and techniques found that are identified as the methods which will have the greatest effect on urban planning projects toward sustainable outcomes.

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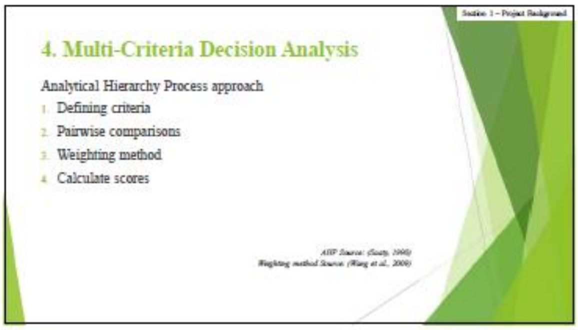
Section 1 – Project Background
4. Multi-Criteria Decision Analysis
Analytical Hierarchy Process approach
1. Defining criteria
2. Pairwise comparisons
3. Weighting method
4. Calculate scores

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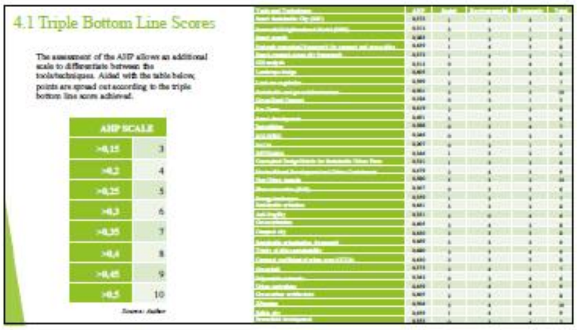
4.1 Triple Bottom Line Scores
The assessment of the AHP allows an additional scale to differentiate between the tools/techniques. Aided with the table below, points are spread out according to the triple bottom line score achieved.
AHP SCALE
>0,15 3
>0,2 4
>0,25 5
>0,3 6
>0,35 7
>0,4 8
>0,45 9
>0,5 10
Source: Author

11


Section 2 – Framework Development
5. Requirements Specification
The objective of the requirements specification is to identify the requirements, restrictions and boundaries contributing toward a research product that achieves the aim of the research.
The aim of the research is to develop a research product that contributes to the successful transition of city sustainability, to mitigate the challenges and safeguards the future prosperity in developing countries urban planning.
Supporting a balance between the social, environmental, and economic stability within an urban system.

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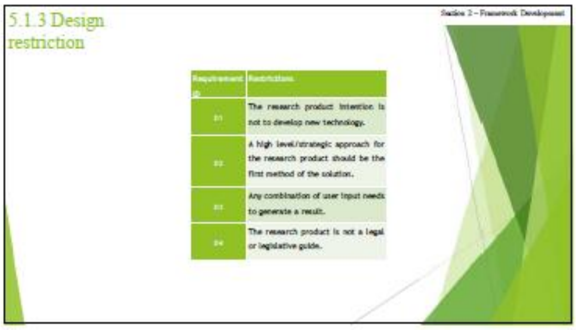


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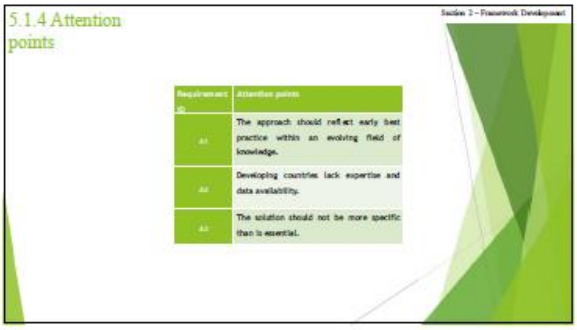


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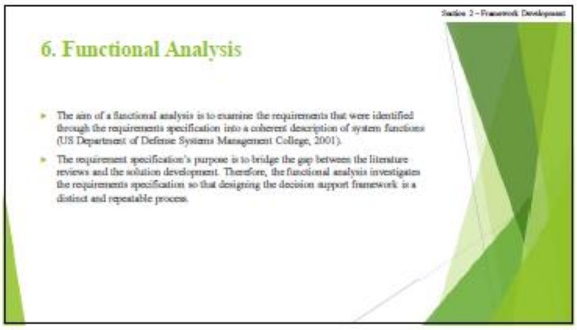


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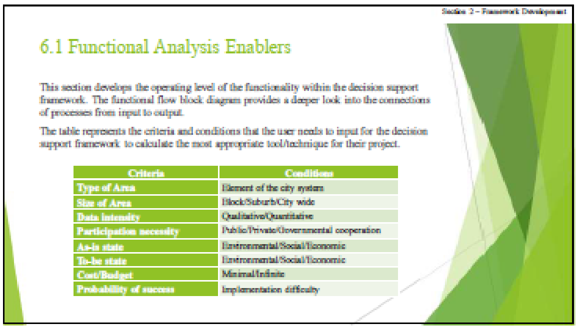


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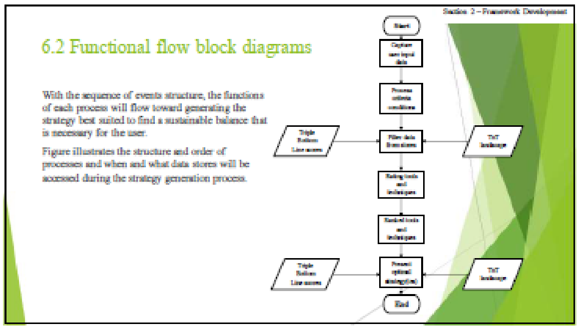


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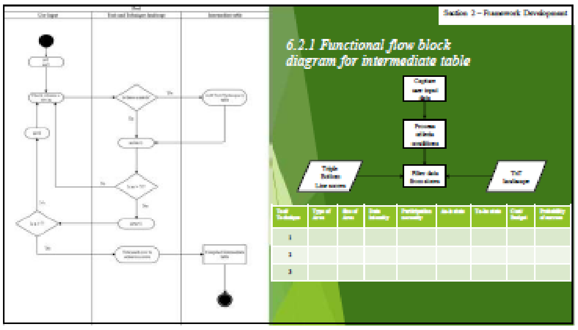


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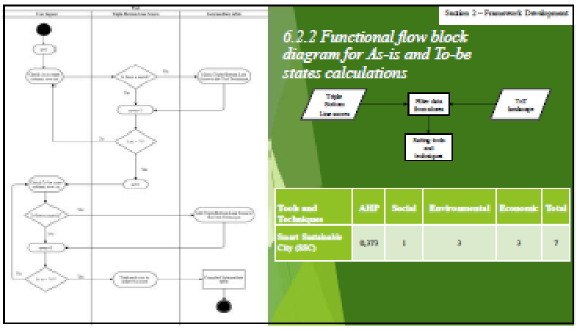


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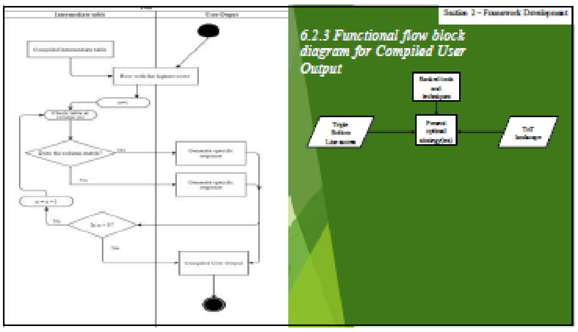


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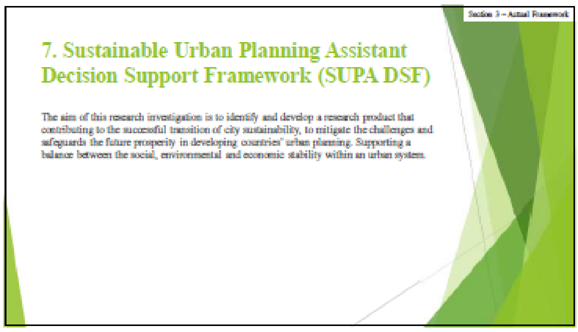


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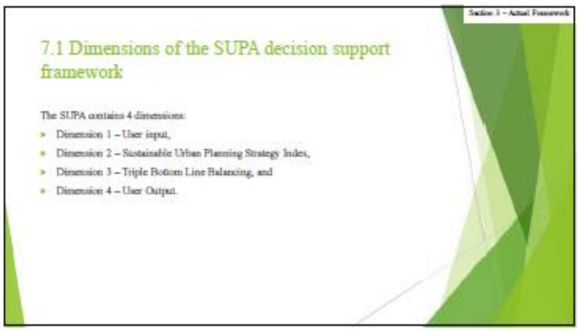


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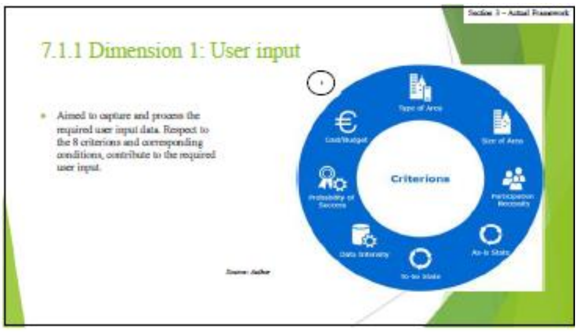


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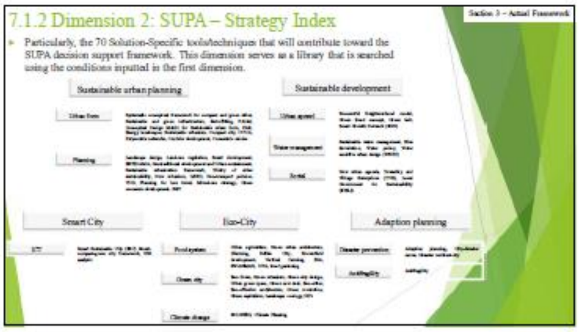


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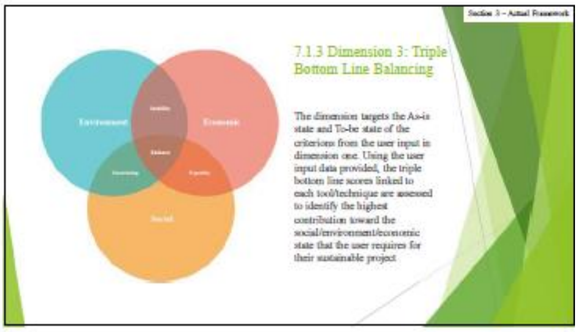


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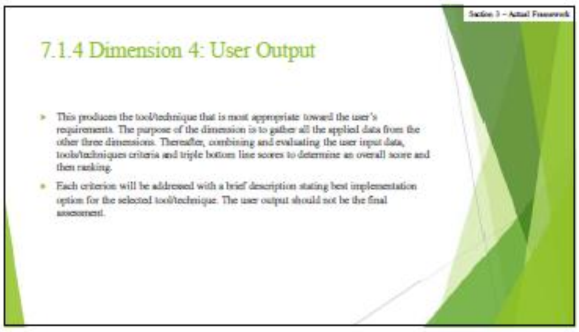


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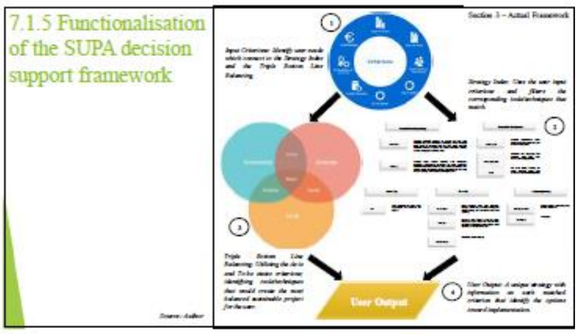


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Section 3 – Actual Framework
Research Aim and Objectives
The aim of this research investigation is to identify and develop a research product that Contributing to the successful transition of city sustainability, to mitigate the challenges and safeguards the future prosperity in developing countries' urban planning. Supporting there is a balance between the social, environmental and economic stability within an urban system.
Perform a requirements specification to design a research product.
Identify the connections with the challenges addressed in the Tools and Techniques landscape using a multi-criteria decision analysis.
Identify the requirements, restrictions and boundaries contributing toward a research product that achieves the aim of the research.
Develop a research product for sustainable urban planning in developing countries.
Undertake a functional analysis of the requirements specification.
Design a research product that will address the aim of the study.

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Theoretical verification questionnaire
3 Parts
Part 1 - Research Verification
Part 2 - Framework Dimensions
Part 3 - Framework Value

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Theoretical verification questionnaire
Part 1: Research verification
Does the research contain all the applicable context-specific elements (challenges, methods and requirements) to assist in understanding the sustainable urban planning in developing countries? If not, could you provide any guidance on additional elements?
Will the requirements specification achieve the research objective?

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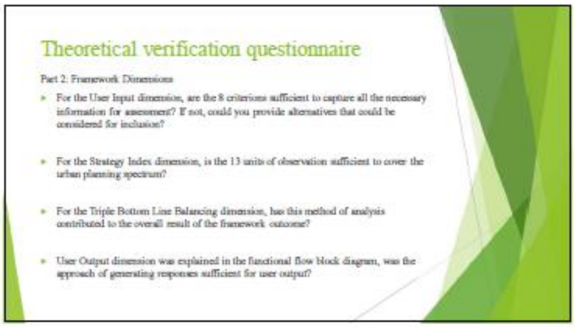
Theoretical verification questionnaire
Part 2: Framework Dimensions
For the User Input dimension, are the 8 criterions sufficient to capture all the necessary information for assessment? If not, could you provide alternatives that could be considered for inclusion?
For the Strategy Index dimension, is the 13 units of observation sufficient to cover the urban planning spectrum?
For the Triple Bottom Line Balancing dimension, has this method of analysis contributed to the overall result of the framework outcome?
User Output dimension was explained in the functional flow block diagram, was the approach of generating responses sufficient for user output?

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Theoretical verification questionnaire
Part 3: Framework Value
Could the SUPA framework contribute toward improving sustainable urban planning in developing countries?
Are there any bodies of literature that you feel have been excluded that should be considered for inclusion in the development of the proposed framework?

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# Appendix C – SUPA DSF user output for each case study



## C.1 – Urbanisation, trinity of cities sustainability

| *CASE 1: Urbanisation* | | |
|---|---|---|
| *Criteria* | | *Conditions* |
| | Type of Area | Commercial |
| | Size of Area | City wide |
| | Data intensity | Qualitative |
| | Participation necessity | Public |
| | As-is state | Environmental |
| | To-be state | Economic, Environmental and Social |
| | Cost/Budget | Minimal |
| | Probability of success | Low |

*Table C. 1 Urbanisation AHP assessment for Urban System Elements*

| **Urbanisation AHP assessment for Urban System Elements** | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | B=i | | | | | | | | | | | | | | | | | | | | 0,160 |
| | | **Resi** | **Comme** | **Busi** | **Indus** | **Commu** | **Rec** | **Bio** | **Infra** | **Trans** | **Socio** | **avg** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Sj** | | **Norm** |
| | **Residential** | | 1 | 5 | 3 | 1 | 5 | 3 | 1 | 1 | 3 | 2,56 | | 2,420 | 5,975 | 0,198 | 2,420 | 5,975 | 0,198 | 2,420 | 2,420 | 0,198 | 1,491 | Residential | 0,238 |
| | **Commercial** | 1 | | 3 | 1 | | 5 | 1 | | | 1 | 2,00 | 2,420 | | 0,198 | 2,420 | | 5,975 | 2,420 | | | 2,420 | 1,259 | Commercial | 0,201 |
| | **Business** | | | | 1 | | 1 | | | | | 1,00 | | | | 2,420 | | 2,420 | | | | | | | |
| | **Industrial** | | 1 | 1 | | | 1 | | | | | 1,00 | | 2,420 | 2,420 | | | 2,420 | | | | | 0,852 | Industrial | 0,136 |
| | **Community** | 1 | 3 | 5 | 5 | | 1 | 3 | 1 | 3 | 1 | 2,56 | 2,420 | 0,198 | 5,975 | 5,975 | | 2,420 | 0,198 | 2,420 | 0,198 | 2,420 | | | |
| A=j | **Recreational** | | | 1 | 1 | 1 | | | | | 1 | 1,00 | | | 2,420 | 2,420 | 2,420 | | | | | 2,420 | | | |
| | **Biophysical assets** | | 1 | 3 | 5 | | 5 | | 3 | 5 | 3 | 3,57 | | 2,420 | 0,198 | 5,975 | | 5,975 | | 0,198 | 5,975 | 0,198 | | | |
| | **Infrastructure** | 1 | 5 | 5 | 5 | 1 | 3 | | | 1 | | 3,00 | 2,420 | 5,975 | 5,975 | 5,975 | 2,420 | 0,198 | | | 2,420 | | | | |
| | **Transport network** | 1 | 5 | 5 | 3 | | 3 | | 1 | | 1 | 2,71 | 2,420 | 5,975 | 5,975 | 0,198 | | 0,198 | | 2,420 | | 2,420 | 1,400 | Transport network | 0,223 |
| | **Socio-economic activities** | | 1 | 3 | 5 | 1 | 1 | | 3 | 1 | | 2,14 | | 2,420 | 0,198 | 5,975 | 2,420 | 2,420 | | 0,198 | 2,420 | | 1,267 | Socio-economic activities | 0,202 |

*Table C. 2 Total AHP score for Urbanisation case study*

| Tool/Technique | Urban System Elements | Urbanisation AHP score | SDGs | Urbanisation AHP score | Total |
|---|---|---|---|---|---|
| **Trinity of Cities Sustainability** | Residential, Commercial, Business, Community, Industrial, Transport, Socio-economic | **1.000** | 3, 9, 11, 12, 13 | **0.362** | **1.362** |
| **Sustainable Urbanisation Framework** | Residential, Commercial, Community, Industrial, Infrastructure, Transport | **0.798** | 11, 12, 13 | **0.290** | **1.088** |
| **Conceptual Design Matrix for Sustainable Urban form** | Residential, Commercial, Community, Recreation | **0.439** | 9, 11, 12, 13 | **0.362** | **0.801** |

*Table C. 3: Urbanisation AHP assessment for SDGs*

| | | B=i | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,094 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | avg | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Sj | | Norm |
| | 1 | | 1 | 5 | 5 | 5 | 3 | 1 | 3 | 1 | 1 | | | 5 | 5 | 3 | 3 | 5 | 3,29 | | 5,224 | 2,939 | 2,939 | 2,939 | 0,082 | 5,224 | 0,082 | 5,224 | 5,224 | | | 2,939 | 2,939 | 0,082 | 0,082 | 2,939 | 1,971 | 1 | 0,184 |
| | 2 | 1 | | 5 | 5 | 5 | 3 | 1 | 3 | 3 | 3 | | | 5 | 3 | 3 | 3 | 5 | 3,43 | 5,898 | | 2,469 | 2,469 | 2,469 | 0,184 | 5,898 | 0,184 | 0,184 | 0,184 | | | 2,469 | 0,184 | 0,184 | 0,184 | 2,469 | | | |
| | 3 | | | | 3 | 1 | 1 | | 3 | 3 | 1 | | | 1 | 3 | 1 | 1 | 3 | 1,91 | | | | 1,190 | 0,826 | 0,826 | | 1,190 | 1,190 | 0,826 | | | 0,826 | 1,190 | 0,826 | 0,826 | 1,190 | | | |
| | 4 | | | | | 3 | | | 1 | 1 | 1 | | | 1 | 3 | 1 | 1 | 3 | 1,67 | | | | | 1,778 | | | 0,444 | 0,444 | 0,444 | | | 0,444 | 1,778 | 0,444 | 0,444 | 1,778 | | | |
| | 5 | | | 1 | | | | | 1 | 1 | 1 | | | | 3 | 1 | 1 | 5 | 1,75 | | | 0,563 | 3,063 | | | | 0,563 | 0,563 | 0,563 | | | | 1,563 | 0,563 | 0,563 | 10,563 | | | |
| | 6 | | | 1 | 3 | 3 | | 3 | 5 | 3 | 3 | | 1 | 1 | 1 | 1 | 3 | 5 | 2,54 | | | 2,367 | 0,213 | 0,213 | | 0,213 | 6,059 | 0,213 | 0,213 | | 2,367 | 2,367 | 2,367 | 2,367 | 0,213 | 6,059 | 1,588 | 6 | 0,149 |
| | 7 | 1 | 1 | 3 | 3 | 3 | | | 3 | 1 | 3 | 1 | | 3 | 3 | 1 | 3 | 5 | 2,43 | 2,041 | 2,041 | 0,327 | 0,327 | 0,327 | | | 0,327 | 2,041 | 0,327 | 2,041 | | 0,327 | 0,327 | 2,041 | 0,327 | 6,612 | 1,394 | 7 | 0,130 |
| A=j | 8 | | 3 | | 1 | 1 | | | | | 1 | | | | | | | 1 | 1,40 | | 2,560 | | 0,160 | 0,160 | | | | | 0,160 | | | | | | | 0,160 | 0,566 | 8 | 0,053 |
| | 9 | 1 | | | 1 | 1 | | 1 | 3 | | 1 | | | | 1 | | | 3 | 1,50 | 0,250 | | | 0,250 | 0,250 | | 0,250 | 2,250 | | 0,250 | | | | 0,250 | | | 2,250 | 0,775 | 9 | 0,072 |
| | 10 | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | | 1 | 3 | 1 | 1 | 5 | 1,55 | 0,298 | | 0,298 | 0,298 | 0,298 | | | 0,298 | 0,298 | | | | 0,298 | 2,116 | 0,298 | 0,298 | 11,934 | 1,293 | 10 | 0,121 |
| | 11 | 3 | 3 | 3 | 3 | 5 | 3 | 1 | 5 | 3 | 3 | | 3 | 1 | 3 | 1 | 3 | 5 | 3,00 | 0,000 | 0,000 | 0,000 | 0,000 | 4,000 | 0,000 | 4,000 | 4,000 | 0,000 | 0,000 | | 0,000 | 4,000 | 0,000 | 4,000 | 0,000 | 4,000 | 1,549 | 11 | 0,145 |
| | 12 | 3 | 3 | 3 | 3 | 5 | 1 | 3 | 5 | 3 | 3 | | | 1 | 3 | 1 | 3 | 5 | 3,00 | 0,000 | 0,000 | 0,000 | 0,000 | 4,000 | 4,000 | 0,000 | 4,000 | 0,000 | 0,000 | | | 4,000 | 0,000 | 4,000 | 0,000 | 4,000 | 1,549 | 12 | 0,145 |
| | 13 | | | 1 | 1 | 3 | 1 | | 5 | 3 | 1 | 1 | 1 | | 3 | 3 | 3 | 3 | 2,23 | | | 1,515 | 1,515 | 0,592 | 1,515 | | 7,669 | 0,592 | 1,515 | 1,515 | 1,515 | | 0,592 | 0,592 | 0,592 | 0,592 | | | |
| | 14 | | | | | | 1 | | 3 | 1 | | | | | | | | 3 | 2,00 | | | | | | 1,000 | | 1,000 | 1,000 | | | | | | | | 1,000 | | | |
| | 15 | | | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | | 3 | | 3 | 5 | 1,92 | | | 0,852 | 0,852 | 0,852 | 0,852 | 0,852 | 1,160 | 1,160 | 0,852 | 0,852 | 0,852 | | 1,160 | | 1,160 | 9,467 | | | |
| | 16 | | | 1 | 1 | 1 | | | 3 | 3 | 1 | | | | 3 | | | 5 | 2,25 | | | 1,563 | 1,563 | 1,563 | | | 0,563 | 0,563 | 1,563 | | | | 0,563 | | | 7,563 | | | |
| | 17 | | | | | | | | 1 | | | | | | | | | | 1,00 | | | | | | | | 0,000 | | | | | | | | | | | | |

## C.2 – Urban sprawl, neotraditional and urban containment

| *CASE 2: Urban Sprawl* | | |
|---|---|---|
| *Criteria* | | *Conditions* |
| | Type of Area | Transport network |
| | Size of Area | City Wide |
| | Data intensity | Quantitative |
| | Participation necessity | Public |
| | As-is state | Economic |
| | To-be state | Economic, Environmental and Social |
| | Cost/Budget | Minimal |
| | Probability of success | Medium |

*Table C. 4: Urban Sprawl AHP assessment for Urban System Elements*

| | | B=i | | | | | | | | | | | | | | | | | | | | | | | 0,107 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A=j | | **Resi** | **Comme** | **Busi** | **Indus** | **Commu** | **Rec** | **Bio** | **Infra** | **Trans** | **Socio** | **avg** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Sj** | | **Norm** |
| | **Residential** | | 1 | 5 | 3 | 1 | 5 | 3 | 1 | 1 | 3 | 2,56 | | 2,420 | 5,975 | 0,198 | 2,420 | 5,975 | 0,198 | 2,420 | 2,420 | 0,198 | 1,491 | Residential | 0,159 |
| | **Commercial** | 1 | | 3 | 1 | | 5 | 1 | | | 1 | 2,00 | 2,420 | | 0,198 | 2,420 | | 5,975 | 2,420 | | | 2,420 | | | |
| | **Business** | | | | 1 | | 1 | | | | | 1,00 | | | | 2,420 | | 2,420 | | | | | 0,696 | Business | 0,074 |
| | **Industrial** | | 1 | 1 | | | 1 | | | | | 1,00 | | 2,420 | 2,420 | | | 2,420 | | | | | | | |
| | **Community** | 1 | 3 | 5 | 5 | | 1 | 3 | 1 | 3 | 1 | 2,56 | 2,420 | 0,198 | 5,975 | 5,975 | | 2,420 | 0,198 | 2,420 | 0,198 | 2,420 | 1,491 | Community | 0,159 |
| | **Recreational** | | | 1 | 1 | 1 | | | | | 1 | 1,00 | | | 2,420 | 2,420 | 2,420 | | | | | 2,420 | | | |
| | **Biophysical assets** | | 1 | 3 | 5 | | 5 | | 3 | 5 | 3 | 3,57 | | 2,420 | 0,198 | 5,975 | | 5,975 | | 0,198 | 5,975 | 0,198 | 1,447 | Biophysical assets | 0,154 |
| | **Infrastructure** | 1 | 5 | 5 | 5 | 1 | 3 | | | 1 | | 3,00 | 2,420 | 5,975 | 5,975 | 5,975 | 2,420 | 0,198 | | | 2,420 | | 1,593 | Infrastructure | 0,170 |
| | **Transport network** | 1 | 5 | 5 | 3 | | 3 | | 1 | | 1 | 2,71 | 2,420 | 5,975 | 5,975 | 0,198 | | 0,198 | | 2,420 | | 2,420 | 1,400 | Transport network | 0,149 |
| | **Socio-economic activities** | | 1 | 3 | 5 | 1 | 1 | | 3 | 1 | | 2,14 | | 2,420 | 0,198 | 5,975 | 2,420 | 2,420 | | 0,198 | 2,420 | | 1,267 | Socio-economic activities | 0,135 |

*Table C. 5: Total AHP scores for Urban Sprawl case study*

| Tool/Technique | Urban System Elements | Urban Sprawl AHP score | SDGs | Urban Sprawl AHP score | Total |
|---|---|---|---|---|---|
| **New Urban Agenda** | Community, Infrastructure, Recreation, Biophysical | **0.618** | 3, 4, 6, 7, 8, 10, 11, 12, 13, 16 | **0.750** | **1.368** |
| **Neotraditional Development and Urban Containment** | Residential, Commercial, Business, Biophysical, Transport, Socio-economic | **0.671** | 2, 3, 11, 12, 13 | **0.604** | **1.275** |
| **Eco-effective Architecture** | Commercial, Community, Biophysical, Infrastructure | **0.483** | 2, 3, 6, 11, 12, 13 | **0.772** | **1.255** |

*Table C. 6: Urban Sprawl AHP assessment for SDGs*

| | | B=i | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **avg** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Diff** | **Sj** | | **Norm** |
| | **1** | | 1 | 5 | 5 | 5 | 3 | 1 | 3 | 1 | 1 | | | 5 | 5 | 3 | 3 | 5 | 3,29 | | 5,224 | 2,939 | 2,939 | 2,939 | 0,082 | 5,224 | 0,082 | 5,224 | 5,224 | | | 2,939 | 2,939 | 0,082 | 0,082 | 2,939 | | | |
| | **2** | 1 | | 5 | 5 | 5 | 3 | 1 | 3 | 3 | 3 | | | 5 | 3 | 3 | 3 | 5 | 3,43 | 5,898 | | 2,469 | 2,469 | 2,469 | 0,184 | 5,898 | 0,184 | 0,184 | 0,184 | | | 2,469 | 0,184 | 0,184 | 0,184 | 2,469 | 1,595 | **2** | 0,168 |
| | **3** | | | | 3 | 1 | 1 | | 3 | 3 | 1 | | | 1 | 3 | 1 | 1 | 3 | 1,91 | | | | 1,190 | 0,826 | 0,826 | | 1,190 | 1,190 | 0,826 | | | 0,826 | 1,190 | 0,826 | 0,826 | 1,190 | 1,044 | **3** | 0,110 |
| | **4** | | | | | 3 | | | 1 | 1 | 1 | | | 1 | 3 | 1 | 1 | 3 | 1,67 | | | | | 1,778 | | | 0,444 | 0,444 | 0,444 | | | 0,444 | 1,778 | 0,444 | 0,444 | 1,778 | | | |
| | **5** | | | 1 | | | | | 1 | 1 | 1 | | | | 3 | 1 | 1 | 5 | 1,75 | | | 0,563 | 3,063 | | | | 0,563 | 0,563 | 0,563 | | | | 1,563 | 0,563 | 0,563 | 10,563 | | | |
| | **6** | | | 1 | 3 | 3 | | 3 | 5 | 3 | 3 | | 1 | 1 | 1 | 1 | 3 | 5 | 2,54 | | | 2,367 | 0,213 | 0,213 | | 0,213 | 6,059 | 0,213 | 0,213 | | 2,367 | 2,367 | 2,367 | 2,367 | 0,213 | 6,059 | 1,588 | **6** | 0,167 |
| | **7** | 1 | 1 | 3 | 3 | 3 | | | 3 | 1 | 3 | 1 | | 3 | 3 | 1 | 3 | 5 | 2,43 | 2,041 | 2,041 | 0,327 | 0,327 | 0,327 | | | 0,327 | 2,041 | 0,327 | 2,041 | | 0,327 | 0,327 | 2,041 | 0,327 | 6,612 | 1,394 | **7** | 0,147 |
| | **8** | | 3 | | 1 | 1 | | | | | 1 | | | | | | | 1 | 1,40 | | 2,560 | | 0,160 | 0,160 | | | | | 0,160 | | | | | | | 0,160 | | | |
| **A=j** | **9** | 1 | | | 1 | 1 | | 1 | 3 | | 1 | | | | 1 | | | 3 | 1,50 | 0,250 | | | 0,250 | 0,250 | | 0,250 | 2,250 | | 0,250 | | | | 0,250 | | | 2,250 | 0,775 | **9** | 0,082 |
| | **10** | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | | 1 | 3 | 1 | 1 | 5 | 1,55 | 0,298 | | 0,298 | 0,298 | 0,298 | | | 0,298 | 0,298 | | | | 0,298 | 2,116 | 0,298 | 0,298 | 11,934 | | | |
| | **11** | 3 | 3 | 3 | 3 | 5 | 3 | 1 | 5 | 3 | 3 | | 3 | 1 | 3 | 1 | 3 | 5 | 3,00 | 0,000 | 0,000 | 0,000 | 0,000 | 4,000 | 0,000 | 4,000 | 4,000 | 0,000 | 0,000 | | 0,000 | 4,000 | 0,000 | 4,000 | 0,000 | 4,000 | 1,549 | **11** | 0,163 |
| | **12** | 3 | 3 | 3 | 3 | 5 | 1 | 3 | 5 | 3 | 3 | | | 1 | 3 | 1 | 3 | 5 | 3,00 | 0,000 | 0,000 | 0,000 | 0,000 | 4,000 | 4,000 | 0,000 | 4,000 | 0,000 | 0,000 | | | 4,000 | 0,000 | 4,000 | 0,000 | 4,000 | 1,549 | **12** | 0,163 |
| | **13** | | | 1 | 1 | 3 | 1 | | 5 | 3 | 1 | 1 | 1 | | 3 | 3 | 3 | 3 | 2,23 | | | 1,515 | 1,515 | 0,592 | 1,515 | | 7,669 | 0,592 | 1,515 | 1,515 | 1,515 | | 0,592 | 0,592 | 0,592 | 0,592 | | | |
| | **14** | | | | | | 1 | | 3 | 1 | | | | | | | | 3 | 2,00 | | | | | | 1,000 | | 1,000 | 1,000 | | | | | | | | 1,000 | | | |
| | **15** | | | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | | 3 | | 3 | 5 | 1,92 | | | 0,852 | 0,852 | 0,852 | 0,852 | 0,852 | 1,160 | 1,160 | 0,852 | 0,852 | 0,852 | | 1,160 | | 1,160 | 9,467 | | | |
| | **16** | | | 1 | 1 | 1 | | | 3 | 3 | 1 | | | | 3 | | | 5 | 2,25 | | | 1,563 | 1,563 | 1,563 | | | 0,563 | 0,563 | 1,563 | | | | 0,563 | | | 7,563 | | | |
| | **17** | | | | | | | | 1 | | | | | | | | | | 1,00 | | | | | | | | 0,000 | | | | | | | | | | | | |

## C.3 – Population growth, new urban agenda

| *CASE 3: Population Growth* | | |
|---|---|---|
| *Criteria* | | *Conditions* |
| | Type of Area | Residential |
| | Size of Area | City Wide |
| | Data intensity | Quantitative |
| | Participation necessity | Governmental |
| | As-is state | Environmental |
| | To-be state | Environmental and Economic |
| | Cost/Budget | Minimal |
| | Probability of success | Medium |

*Table C. 7: Population Growth AHP assessment for Urban System Elements*

| | | B=i | | | | | | | | | | | | | | | | | | | | | | | 0,137 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A=j | | Resi | Comme | Busi | Indus | Commu | Rec | Bio | Infra | Trans | Socio | avg | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Sj | | Norm |
| | **Residential** | | 1 | 5 | 3 | 1 | 5 | 3 | 1 | 1 | 3 | 2,56 | | 2,420 | 5,975 | 0,198 | 2,420 | 5,975 | 0,198 | 2,420 | 2,420 | 0,198 | 1,491 | Residential | 0,205 |
| | **Commercial** | 1 | | 3 | 1 | | 5 | 1 | | | 1 | 2,00 | 2,420 | | 0,198 | 2,420 | | 5,975 | 2,420 | | | 2,420 | | | |
| | **Business** | | | | 1 | | 1 | | | | | 1,00 | | | | 2,420 | | 2,420 | | | | | | | |
| | **Industrial** | | 1 | 1 | | | 1 | | | | | 1,00 | | 2,420 | 2,420 | | | 2,420 | | | | | | | |
| | **Community** | 1 | 3 | 5 | 5 | | 1 | 3 | 1 | 3 | 1 | 2,56 | 2,420 | 0,198 | 5,975 | 5,975 | | 2,420 | 0,198 | 2,420 | 0,198 | 2,420 | 1,491 | Community | 0,205 |
| | **Recreational** | | | 1 | 1 | 1 | | | | | 1 | 1,00 | | | 2,420 | 2,420 | 2,420 | | | | | 2,420 | | | |
| | **Biophysical assets** | | 1 | 3 | 5 | | 5 | | 3 | 5 | 3 | 3,57 | | 2,420 | 0,198 | 5,975 | | 5,975 | | 0,198 | 5,975 | 0,198 | 1,447 | Biophysical assets | 0,199 |
| | **Infrastructure** | 1 | 5 | 5 | 5 | 1 | 3 | | | 1 | | 3,00 | 2,420 | 5,975 | 5,975 | 5,975 | 2,420 | 0,198 | | | 2,420 | | 1,593 | Infrastructure | 0,219 |
| | **Transport network** | 1 | 5 | 5 | 3 | | 3 | | 1 | | 1 | 2,71 | 2,420 | 5,975 | 5,975 | 0,198 | | 0,198 | | 2,420 | | 2,420 | | | |
| | **Socio-economic activities** | | 1 | 3 | 5 | 1 | 1 | | 3 | 1 | | 2,14 | | 2,420 | 0,198 | 5,975 | 2,420 | 2,420 | | 0,198 | 2,420 | | 1,267 | Socio-economic activities | 0,174 |

*Table C. 8: Total AHP scores for Urban Sprawl case study*

| Tool/Technique | Urban System Elements | Population Growth AHP score | SDGs | Population Growth AHP score | Total |
|---|---|---|---|---|---|
| **New Urban Agenda** | Community, Infrastructure, Recreation, Biophysical | **0.795** | 3, 4, 6, 7, 8, 10, 11, 13, 16 | **0.659** | **1.454** |
| **ZFarming** | Residential, Community, Commercial, Biophysical, Infrastructure | **0.826** | 2, 3, 6, 12, 13, 15 | **0.400** | **1.226** |
| **Eco-effective architecture** | Commercial, Community, Biophysical, Infrastructure | **0.622** | 2, 3, 6, 11, 12, 13 | **0.548** | **1.170** |

*Table C. 9: Population Growth AHP assessment for SDGs*

| | B=i | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,096 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | avg | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Diff | Sj | | Norm |
| | 1 | | 1 | 5 | 5 | 5 | 3 | 1 | 3 | 1 | 1 | | | 5 | 5 | 3 | 3 | 5 | 3,29 | | 5,224 | 2,939 | 2,939 | 2,939 | 0,082 | 5,224 | 0,082 | 5,224 | 5,224 | | | 2,939 | 2,939 | 0,082 | 0,082 | 2,939 | 1,971 | 1 | 0,188 |
| | 2 | 1 | | 5 | 5 | 5 | 3 | 1 | 3 | 3 | 3 | | | 5 | 3 | 3 | 3 | 5 | 3,43 | 5,898 | | 2,469 | 2,469 | 2,469 | 0,184 | 5,898 | 0,184 | 0,184 | 0,184 | | | 2,469 | 0,184 | 0,184 | 0,184 | 2,469 | 1,595 | 2 | 0,152 |
| | 3 | | | | 3 | 1 | 1 | | 3 | 3 | 1 | | | 1 | 3 | 1 | 1 | 3 | 1,91 | | | | 1,190 | 0,826 | 0,826 | | 1,190 | 1,190 | 0,826 | | | 0,826 | 1,190 | 0,826 | 0,826 | 1,190 | 1,044 | 3 | 0,100 |
| | 4 | | | | | 3 | | | 1 | 1 | 1 | | | 1 | 3 | 1 | 1 | 3 | 1,67 | | | | | 1,778 | | | 0,444 | 0,444 | 0,444 | | | 0,444 | 1,778 | 0,444 | 0,444 | 1,778 | 0,894 | 4 | 0,085 |
| | 5 | | | 1 | | | | | 1 | 1 | 1 | | | | 3 | 1 | 1 | 5 | 1,75 | | | 0,563 | 3,063 | | | | 0,563 | 0,563 | 0,563 | | | | 1,563 | 0,563 | 0,563 | 10,563 | | | |
| | 6 | | | 1 | 3 | 3 | | 3 | 5 | 3 | 3 | | 1 | 1 | 1 | 1 | 3 | 5 | 2,54 | | | 2,367 | 0,213 | 0,213 | | 0,213 | 6,059 | 0,213 | 0,213 | | 2,367 | 2,367 | 2,367 | 2,367 | 0,213 | 6,059 | | | |
| | 7 | 1 | 1 | 3 | 3 | 3 | | | 3 | 1 | 3 | 1 | | 3 | 3 | 1 | 3 | 5 | 2,43 | 2,041 | 2,041 | 0,327 | 0,327 | 0,327 | | | 0,327 | 2,041 | 0,327 | 2,041 | | 0,327 | 0,327 | 2,041 | 0,327 | 6,612 | | | |
| A=j | 8 | | 3 | | 1 | 1 | | | | | 1 | | | | | | | 1 | 1,40 | | 2,560 | | 0,160 | 0,160 | | | | | 0,160 | | | | | | | 0,160 | 0,566 | 8 | 0,054 |
| | 9 | 1 | | | 1 | 1 | | 1 | 3 | | 1 | | | | 1 | | | 3 | 1,50 | 0,250 | | | 0,250 | 0,250 | | 0,250 | 2,250 | | 0,250 | | | | 0,250 | | | 2,250 | | | |
| | 10 | 1 | | 1 | 1 | 1 | | | 1 | 1 | | | | 1 | 3 | 1 | 1 | 5 | 1,55 | 0,298 | | 0,298 | 0,298 | 0,298 | | | 0,298 | 0,298 | | | | 0,298 | 2,116 | 0,298 | 0,298 | 11,934 | 1,293 | 10 | 0,124 |
| | 11 | 3 | 3 | 3 | 3 | 5 | 3 | 1 | 5 | 3 | 3 | | 3 | 1 | 3 | 1 | 3 | 5 | 3,00 | 0,000 | 0,000 | 0,000 | 0,000 | 4,000 | 0,000 | 4,000 | 4,000 | 0,000 | 0,000 | | 0,000 | 4,000 | 0,000 | 4,000 | 0,000 | 4,000 | 1,549 | 11 | 0,148 |
| | 12 | 3 | 3 | 3 | 3 | 5 | 1 | 3 | 5 | 3 | 3 | | | 1 | 3 | 1 | 3 | 5 | 3,00 | 0,000 | 0,000 | 0,000 | 0,000 | 4,000 | 4,000 | 0,000 | 4,000 | 0,000 | 0,000 | | | 4,000 | 0,000 | 4,000 | 0,000 | 4,000 | 1,549 | 12 | 0,148 |
| | 13 | | | 1 | 1 | 3 | 1 | | 5 | 3 | 1 | 1 | 1 | | 3 | 3 | 3 | 3 | 2,23 | | | 1,515 | 1,515 | 0,592 | 1,515 | | 7,669 | 0,592 | 1,515 | 1,515 | 1,515 | | 0,592 | 0,592 | 0,592 | 0,592 | | | |
| | 14 | | | | | | 1 | | 3 | 1 | | | | | | | | 3 | 2,00 | | | | | | 1,000 | | 1,000 | 1,000 | | | | | | | | 1,000 | | | |
| | 15 | | | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | | 3 | | 3 | 5 | 1,92 | | | 0,852 | 0,852 | 0,852 | 0,852 | 0,852 | 1,160 | 1,160 | 0,852 | 0,852 | 0,852 | | 1,160 | | 1,160 | 9,467 | | | |
| | 16 | | | 1 | 1 | 1 | | | 3 | 3 | 1 | | | | 3 | | | 5 | 2,25 | | | 1,563 | 1,563 | 1,563 | | | 0,563 | 0,563 | 1,563 | | | | 0,563 | | | 7,563 | | | |
| | 17 | | | | | | | | 1 | | | | | | | | | | 1,00 | | | | | | | | 0,000 | | | | | | | | | | | | |